Chapter 1 Master Composter/Recycler Program Overview

The Grant County Master Composter/Recycler Program is a joint effort of Grant County Solid Waste and the WSU Grant/Adams Master Gardener Programs. This text for this program has been adapted from the Clark County, WA Master Composter/Recycler Program.

Volunteer Job Description

Master Composter/Recyclers provide community composting and recycling information to the public and report to the Program Coordinator at Grant County Public Works. Volunteers receive 18 hours of intensive training on home composting methods, troubleshooting, recycling, and general solid waste issues in Grant County. After completing their training, volunteers are requested to share this information with their neighbors. Organizing neighborhood meetings or community classes will be facilitated by either the Public Works Coordinator or the Master Gardener Coordinator.

A. Volunteer Responsibilities

Volunteers must be available for all training sessions and for volunteer service.

Volunteers are expected to become a community waste reduction resource and should be comfortable with public contact, whether in a one-on-one situation, or in a group setting.

Volunteers may be called upon to assist in preparing and staffing exhibits and displays at schools, local stores, garden centers, fairs and community events.

Volunteers will assist in teaching public workshops at various locations.

Chapter 2

Humus, Compost and Soil

A. Objectives

1. Define the inorganic and organic components of soil.
2. Understand the important contributions humus makes to soil.
3. Understand how the Soil Food Web provides plant nutrients.
4. Understand that compost is basically "man-made" humus.

Terms Defined in this Chapter:

Ammonifying bacteria
Ammonium
Buffer
Chemical fertilizer
Denitrifying bacteria
Feedstock
Haber-Bosch Process
Humus
Light fraction
Litter fraction
Loam
Macronutrient
Micronutrient
Nitrifying bacteria
Nitrogen Cycle
Petroleum-based fertilizer
pH
Pore
Soil aggregate
Soil Food Web
Soil texture
Synthesis gas
Tilth

B. Study Materials

What is soil?

To understand the importance of compost, you must understand soil. "***Soil is a mass of materials with pore space, air, and water that permit plant growth***" (ref. Miller, *Soils in our Environment,* p.18). The definition is deliberately broad because soils around the world are incredibly diverse. Soil is basically a complex combination of rock, gravel, sand, silts, clay, soluble minerals and decayed organic material. Soil formation is a slow, continual process. It begins as solid rock weathers and breaks into smaller pieces. Chemical reactions on these smaller rocks, stones and gravel release crystalline minerals. Decaying plants and animals supply organic humus to the mix. Eventually, the rock particles, minerals and humus accumulate enough to form soil. Under ideal conditions, recognizable soil "may develop within 200 years; under less favorable conditions, the time may be extended to several thousand years" (ref. Miller, *Soils in Our Environment*, p.23).

Sand, Silt, and Clay

The inorganic component of soil is made up of particles derived from solid rock. These particles range in size from clay, the smallest, to sand the largest.

Sand: Most ***sand*** is derived from the mineral quartz (silicon dioxide, SiO_2). Individual sand particles range in size from 0.05mm-

2mm in diameter. Individual sand particles can be seen by the naked eye and sand feels gritty to the touch. Because of its large particle size, sand drains very quickly. It cannot trap water to feed plant roots. In addition, sand alone contributes virtually no plant nutrients to the soil; silicon dioxide is essentially inert. In soil, sand particles help form open pores for air and water.

Silt: Chemically, ***silt*** is very similar to sand, but its particles range in size from 0.002mm-0.05mm diameter and can be seen under a microscope. Like sand, silt is nutritionally insignificant.

Clay: Unlike sand and silt, ***clay*** is not simply a tiny chip off the old quartz rock. Clay is made up primarily of silicon, aluminum and oxygen. Clays are "newly formed crystals, re-formed from the soluble products of primary minerals" (ref. Miller, *Soils in our Environment*, p.128). In other words, the soluble fraction of various primary minerals undergoes drastic chemical changes that ultimately lead to the formation of clay crystals. Many specific clay types exist, but all clay particles are less than 0.002mm in diameter. They can only be seen with an electron microscope.

Because of its small pore size, clay has exceptionally high water retention properties. ***Clay also has a negative charge that attracts and holds positively charged ions important to plant nutrition and to the pH (acid-base balance) of the soil*** (see Section 6 of this chapter for details). ***pH*** is a measure of the relative acidity of a compound. The ***pH scale*** ranges from 0 (most acid) to 14 (most basic). A pH of 7 is neutral.

Believe it or not, ***clay is the base for all good soils***. Clay crystals form sticky, lattice-like plate structures, which act, with ***humus***, as cement to bind sand and silt into stable ***soil aggregates.*** The composition of these aggregates determines ***soil texture.***

"***Soil texture***" is the degree of fineness or coarseness of the soil, which is an expression of the percentage of the relative amounts of sand, silt and clay" (ref. Harpstead, *Soil Sci. Simp*., p.23). Table 1 shows the composition of various soil textures. Many soils in Grant County are high in sand, while others ar high in silt. ***Loam*** is considered the ideal soil type.

Table 1. Soil Texture. (Adapted from Miller, *Soils in Our Environment*. p.98)

Soil Texture	**% Sand**	**% Silt**	**% Clay**
Clay	20	20	60
Silt Loam	20	70	10
Sandy Loam	65	25	10
Loam	40	40	20

Sand + Silt + Clay + Humus = Soil

Pure sand, silt and clay are not considered soils because alone they cannot support plant life. Sand, silt and clay form the textural framework or skeleton of soil. Organic matter provides the "body" and plant-sustaining nutrients. In nature, organic matter is slowly broken down by a variety of organisms until it is finally incorporated into humus. Humus then binds sand, silt and clay to form soil. Although the organic substances remaining in humus continue to decompose slowly, humus is *very* stable. In fact, studies with radioactive carbon show that much of the humus in present-day North American soils is derived from plants that died before European colonization (ref. Stevenson, *Humus Chemistry*, p.13).

What is Humus?

In nature, stable, decomposed organic materials are called humus.

How is humus formed?

Humus is basically the end product of organic decomposition. The conversion of organic matter to humus is a slow process of physical and chemical transformation. The easiest way to envision the process of humus formation is to divide the soil into pools or fractions. As organic matter passes from one fraction to the next, it becomes indistinguishable from the soil itself.

Litter fraction. When an organism dies, its body becomes part of the litter fraction. Litter is dead organic matter that lies on the soil surface. When organisms die, their cells rupture and release sugars, starches, complex carbohydrates, proteins and fats. Litter provides a rich diet to soil bacteria, fungi and other microorganisms as well as to earthworms and insects. As they consume the fresh organic litter, these soil dwelling organisms pull the nutrients into the top layer of soil called the light fraction.

Light fraction. The light fraction of the soil consists of "residues in varying stages of decomposition that exists within the soil proper" (ref. Stevenson, Humus Chemistry, p.2). Materials in the light fraction are constantly changing; they provide food for soil organisms, which then provide nutrients for plants. Decomposition in the light fraction can occur quickly or slowly and the rate depends on many variables.

Stable humus fraction. When soil organisms have depleted the easily digestible components of decaying organic matter, some materials, particularly the complex proteins, complex sugars and woody lignins, remain resistant to decomposition. These resistant materials undergo an extremely complex series of biochemical reactions that ultimately converts them to humus (ref. Stevenson, Humus Chemistry, p.210). Humus then combines with clay, sand and silt to form soil.

It is important to keep in mind that when humans control the decomposition process by composting, they are simply "managing an ongoing natural process for their own convenience and utility" (ref. Putnam, Ortho Books: Easy Compost, p. 21). In other words, compost is basically man-made humus.

Humus is not easy to define. "All humus molecules are different from each other and are constantly changing as they are attacked by microbes and further decomposed" (ref. Miller, Soils in Our Environment, p.140). Humus is a diverse system of huge molecules, each made up of simple chemical building blocks that link together to form long looping chains. Each chain contributes unique chemical properties to the humus molecule that affect the physical, chemical and biological properties of the soil. One could think of humus as a vast microscopic octopus, each arm of which has multiple sites to bind clay, hold water, trap oxygen, house microorganisms and capture plant nutrients. As you will learn, humus is truly as complex as the life it supports.

Humus, Plant Growth and the Physical Properties of the Soil

Humus affects many of the physical aspects of soil that directly contribute to plant growth. In fact, even the dark, rich color of soil is due to humus. One of the most important contributions humus makes is in altering soil texture and improving ***tilth.*** Well-aggregated soil is loose and easy to till, in other words, it is said to have ***good tilth***. Humus is vital to forming good tilth in every soil type. As you learned, clay and humus act together to form soil aggregates. ***The degree of soil aggregation is directly related to plant growth because well-aggregated soil is full of pores.*** Pores are simply open spaces between particles within an aggregate and between adjacent aggregates. These pores allow oxygen and water to penetrate, roots to spread and shoots to sprout easily. In addition, well-aggregated soil is less likely to be washed away by moving water, and it supports abundant earthworms and other beneficial soil creatures. Humus-rich soil retains water and acts as a reservoir to plants. In fact, organic matter can hold up to 20 times its weight in water (ref. Stevenson, *Humus Chemistry*, p.15). In contrast, poorly aggregated soils have few pores and do not allow sufficient oxygen and water penetration. Seed germination and root growth suffer from oxygen deprivation and plant health suffers, even when plant nutrients are in good supply.

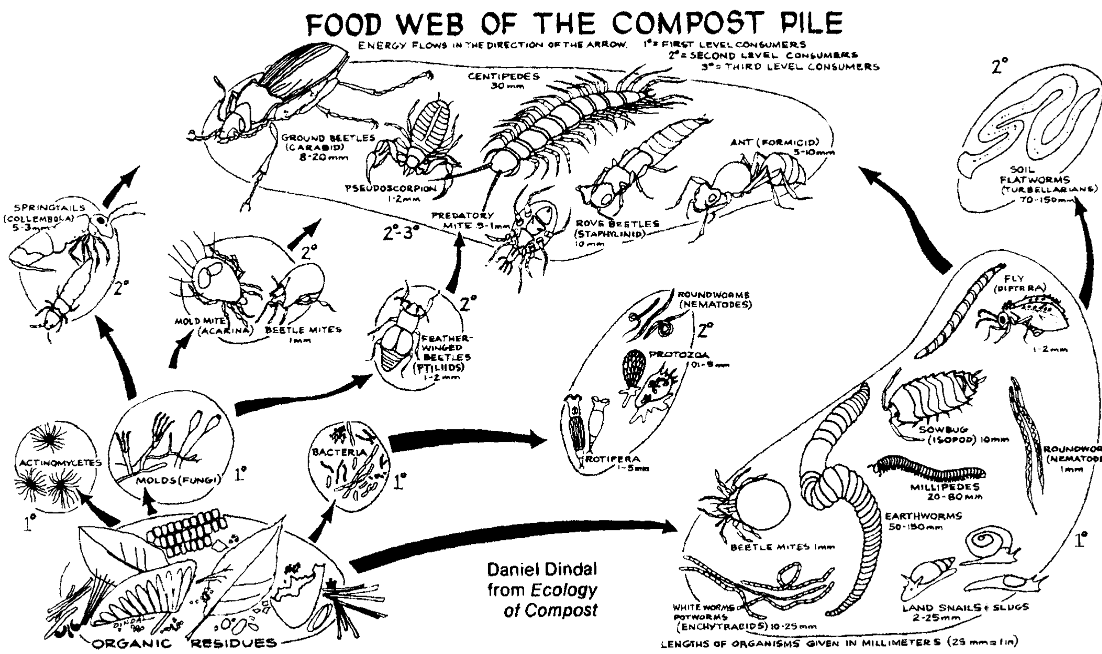
In addition to improving soil texture, the looping arms of a humus molecule act to bind important nutrient minerals and make them available to plant roots. Like clay, humus has a negative charge and can attract and bind positively charged minerals such as potassium (K^+), ammonium ($NH4^+$), sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), manganese (Mn^{2+}), copper (Cu^{2+}) and zinc (Zn^{2+}). Humus also contributes to the pH (acid/base balance) of the soil by acting as a ***buffer***, absorbing excess acid or base and helping the soil maintain a favorable pH. The pH of soil is very important in making nutrients available. ***On a weight basis, humus has a nutrient binding capacity and buffering capacity far greater than clay*** (ref. Miller, *Soils in Our Environment*, p.140). When pH conditions are favorable, the positively charged nutrients bound to soil aggregates are released to plant roots. ***Together, then, clay and humus act as a repository for plant nutrients, preventing rainwater from leaching them away and slowly releasing them to hungry plant roots.*** But where do the plant nutrients come from? In unfertilized soil, decomposing organic matter and the organisms associated with it provide the soil with a pool of vital nutrients.

Humus, Plant Growth and the Soil Food Web

One cannot overstate the importance of decaying organic matter and humus to plant growth. It is a common misconception that soil is an inert substance that passively supports plant roots. Nothing could be farther from the truth. ***Soil is abundantly alive***. As dead organic matter is converted to humus, it feeds a living ecosystem teeming with diverse organisms. ***It is these organisms, not the organic matter itself, that bring life to soil***. Scientists estimate that one teaspoon of healthy soil contains 100 million to 1 billion bacteria, thousands of fungi and protozoa, hundreds of nematodes and insects and ten to fifty earthworms (ref. Edwards, *Soil Biol. Primer,* p. B-2).

As soon as a plant or animal dies, it becomes food for thousands of species that make up the ***Soil (Compost) Food Web*** shown in Figure 1. As you will learn, the organisms involved in making soil are the same organisms we find in a compost pile or worm bin. These organisms include bacteria, fungi, actinomycetes, protozoa, nematodes, insects and earthworms. As soil organisms consume organic waste, they use nitrogen, carbon and

Figure 1. Soil (Compost) Food Web. From Dindal 1971, *Ecology of Compost.*



other digested chemicals to build their cells. As species at the bottom of the food web die, they become food for those higher up. As nutrients move through the web, they are converted into many complex organic forms that ultimately form humus and soil. Plants are nourished when certain species of soil bacteria convert complex organic molecules back to the simple minerals plants require.

In addition to their important role in nutrient cycling, some organisms of the Soil Food Web protect plant roots from pathogens and still others can break down pesticides and pollutants (ref. Edwards, *Soil Biology Primer*, p. C-1). Larger organisms like insects and earthworms act as soil mixers and till organic matter deep into the soil.

The Soil Food Web and Plant Nutrition

"Plants need at least 16 essential elements to grow. The 16 essential nutrients are carbon, oxygen, hydrogen, nitrogen, calcium, potassium, magnesium, phosphorus, sulfur, chlorine, iron, boron, manganese, zinc, copper and molybdenum" (ref. Miller, *Soils in our Environment*, p.261). Hydrogen, oxygen, carbon, nitrogen, potassium and phosphorus are needed in the largest amounts and are considered ***macronutrients***. The other elements, needed in smaller amounts, are considered ***micronutrients***. Plants obtain hydrogen, oxygen and carbon from the air. They must obtain all the other macro and micronutrients from the soil and the "***principal soil storehouse for large amounts of nutrients is soil organic matter***" (ref. Miller, *Soils in our Environment*, p.261).

Unfortunately, many of the nutrients in that organic matter are present in a form that plants cannot use. Plants rely on the organisms of the Soil Food Web, particularly fungi and bacteria, to convert vital nutrients to a plant-friendly form. Soil bacteria are primary decomposers of organic matter and the backbone of the Food Web. Thousands of species are involved and they will be discussed in more detail in Chapter 3.

As a means of illustrating the vital connections between plants, soil, and the organisms of the Soil Food Web, we will focus our discussion on the ***Nitrogen Cycle***. Keep in mind that Food Web organisms are involved in converting many of the nutrients present in the soil to a plant-usable form and that ***similar cycles exist for other nutrients***.

Soil Bacteria and the Nitrogen Cycle

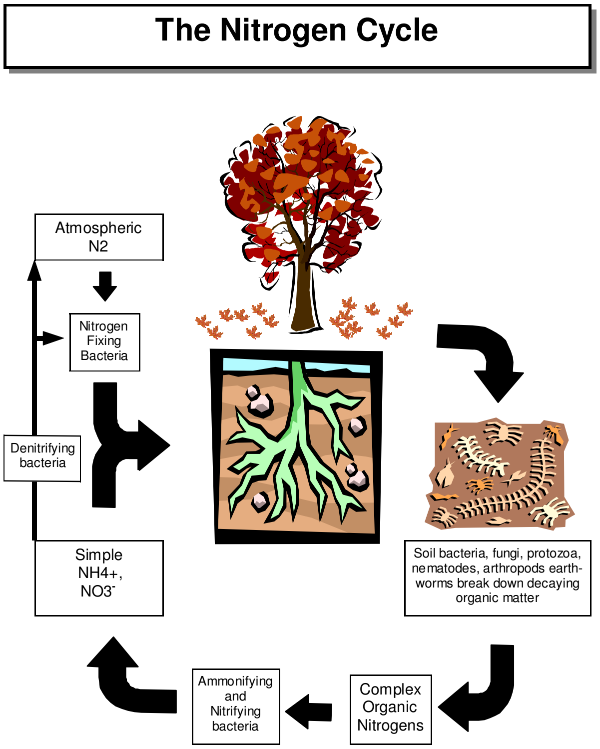
The most important macronutrient is nitrogen. All living organisms require nitrogen in a form they can use to build enzymes, structural proteins, and DNA. Plants derive their nitrogen from the atmosphere and the soil, and animals derive it from eating plants or other animals. Eventually, the nitrogen is returned to the atmosphere. This continual transformation of nitrogen from one form to another is called the ***Nitrogen Cycle.***

Although almost 80% of our atmosphere is made up of nitrogen, atmospheric nitrogen (**N_2**) cannot be used by plants or animals until it is converted to other forms. Atmospheric nitrogen is composed of two nitrogen atoms held together by a very strong chemical bond. Only certain bacteria, volcanic action and lightning can break that bond in nature. Synthetic chemical reactors require extremely high pressure to cleave nitrogen. Of the thousands of bacterial species that thrive in the organic component of the soil, one group, the ***nitrogen fixers***, actually live around or inside the roots of certain plants (mostly legumes) and convert atmospheric nitrogen into ***ammonium (NH_4^+)***, a form the plant can use.

Only certain plants can obtain their nitrogen from nitrogen fixing bacteria. Other plants rely on the ***ammonifying*** and ***nitrifying soil bacteria.*** When the organisms of the Soil Food Web feed on organic plant and animal wastes containing nitrogen, they convert the nitrogen they consume into amino acids (the building blocks of proteins), proteins and other complex organic compounds that they need to grow and reproduce. They then excrete nitrogen containing "manures". Plants cannot use these organic nitrogens. They must rely on ammonifying and nitrifying soil bacteria to convert these organic nitrogen molecules into simple inorganic ammonium (NH_4^+) and nitrates ($NO_3^{-)}$ that can be used by plants. Any ammonium that is not immediately used can bind the negatively charged clay/humus soil aggregates that act as a repository for plant nutrients.

Finally, another specialized group of bacteria, the ***denitrifying bacteria,*** convert nitrates (NO_3^-) back to nitrogen (N_2) where it can be used by nitrogen-fixing bacteria or return to the atmosphere. Figure 2 illustrates the Nitrogen cycle.

Figure 2. The Nitrogen Cycle.



Feeding the Soil versus Feeding the Plant

Any soil is only as good as its organic component. Soils low in organic matter are incapable of providing enough usable nutrients to plants and require chemical fertilizers. Until the early part of the 20th century, all fertilizers were "organic", in other words derived from animal or plant sources. In the years preceding World War I, two German scientists discovered that ammonia could be chemically synthesized from hydrogen and atmospheric nitrogen in the presence of a catalyst under high pressure. Their discovery, called the **Haber-Bosch Process,** revolutionized agriculture.

Chemical fertilizers are often referred to as ***"petroleum-based"*** because petroleum and natural gas are used as ***feedstock*** to produce ammonia. Both serve as sources of hydrogen. Crude oil is used to produce "***synthesis gas***", a mixture of carbon monoxide (CO) and hydrogen (H_2). Synthesis gas is then combined with atmospheric nitrogen in the Haber-Bosch Process to produce ammonia (NH_3). Natural gas, which contains methane (CH_4), is also used as a hydrogen source. The synthetic ammonia can be used directly as a fertilizer or be chemically converted to ammonium nitrate, ammonium sulfate or urea. The potassium (K) and phosphorus (P) usually associated with nitrogen (N) in chemical fertilizers are mined.

Chemical fertilizers bypass most of the slow, steady organic nutrient cycles and simply dump soluble inorganic chemicals into the soil. What the plant cannot immediately use is often washed away or lost to the atmosphere. Excess nitrogen in our streams and ground water reduces the quality of the water, and adversely affects fish, animals and humans. In addition, most chemical fertilizers cannot provide the complex blend of micronutrients plants need for optimal growth and they do nothing to improve the physical structure of the soil. Although chemical fertilizers provide a short-term "fix" that feeds the plant, ***only the slow process of decomposition and humus formation truly feeds the soil***. Table 2, at the end of this chapter, summarizes the important contributions humus makes to the soil.

In Chapters 3, 4, 5 and 6 we will learn how to optimize the natural process of organic decomposition in order to turn our organic wastes into a valuable end product. As you will learn, finished compost and vermicompost are two of the best "meals" you can feed your soil.

Table 2. Contributions of Humus (Adapted from Stevenson, *Humus Chemistry*, p. 15).

Soil Property	Contribution made by Humus	Beneficial Effect on Soil
Color	Rich, dark color is due to decayed organic materials.	Dark color may help soils retain sun's heat.
Soil Structure/Aeration	Combines with clay particles to form soil aggregates.	Aggregates help maintain loose, open, granular soils which permit oxygen transport to plant roots.
Water-Holding Capacity	Organic matter can hold up to 20 times its weight in water.	Aggregate-rich soils allow water to percolate through pores.
Soil Erosion	Aggregates allow greater water retention and percolation.	Soils are less likely to be carried away by moving water.
Acid/Base Balance	Complex humus molecules are good buffers.	Plant roots are not exposed to overly acid or base conditions. Nutrients are more available.
Plant Nutrients	Decomposition of organic materials converts nitrogen, phosphorus and minerals to a form usable by plants.	Organic matter is the source of 90-95% of the nitrogen in unfertilized soil. Humus acts as a repository for plant nutrients.
Trace Metal Availability	Looping arms of the humus molecule act to bind important micronutrients like copper, manganese and zinc.	Vital trace metals are available to plant roots.
Microbial Inoculant	Organic material is rich in beneficial microbes.	Protects roots from predators and pathogens.
Pollutant/Pesticide/ Herbicide Contamination	Binds contaminants and promotes microbial degradation.	Contributes to soil detoxification.

Chapter 3

Biology and Fundamentals of Composting

A. Objectives

1. Understand the role composting plays in solid waste reduction.
2. Define compost and composting.
3. What is aerobic decomposition? Which organisms are important to the process?
4. What makes a pile heat up? What does the temperature curve tell us?
5. Understand the five control factors of a compost pile.
6. Build a "virtual" compost pile using all you have learned in this chapter.
7. Describe finished compost.
8. Understand how to use finished compost.

Terms Defined in this Chapter:

Actinomycetes
Aerobe
Anaerobe
Biologic decomposition
Browns
C:N Ratio
Cellulose
Compost
Compost Food Web
Compost tea: aerated, non-aerated
Composting
Controlled conditions
Dicamba
Enzyme
Finished Compost
Greens
Juglone
Lignin
Mesophile
Psychrophile
Saprophyte
Soil amendment
Thermophile

B. Study Materials

Why compost?

The United States faces a critical landfill shortage. Existing landfills are reaching capacity, and new space is limited. Grant County produces about 90,000 tons of landfill waste each year. The last landfill in Grant County is the Ephrata landfill. The only other open at the start of 2009 was Delano at Grand Coulee. It is now closed and that waste is hauled to Ephrata also. As our garbage bills testify, the cost of waste is high and going higher.

Composting can make an impact. Table 3 shows how much yard waste and food waste end up in the Grant County Waste Stream.

Table 3. Yard and Food Wastes in Grant County Waste Stream. (2008 Grant County Public Works Waste Stream Analyses)

Year	**Yard** Waste (%)	**Food** Waste (%)
2008	6.5	19

6.5% of 90,000 tons means that 5800 tons of yard wastes are being dumped in landfills. Food wastes are the largest single component of waste. They accounted for over 17,000 tons or 19% of the waste stream in 2008, indicating a need for increased education.

Clearly, compostable organic waste should NEVER go to a landfill. Composting is simply ***organic recycling***. But, unlike cans, bottles and paper that can only be reformed into similar products, yard and food wastes can be converted into a ***valuable soil amendment***. As a soil amendment, finished compost improves soils texture, increases the water holding capacity of soil, nourishes plants, and reduces our need for petrochemical fertilizers. There is no recyclable product as versatile or as valuable. Yard and food scraps are simply too precious to waste!

Compost Happens!

Compost happens! Since the dawn of life on earth, and long before man's need for solid waste disposal, nature has been quietly decomposing her dead and returning the nutrients to start another cycle of life. A walk through the forest beautifully demonstrates natural decomposition. As the stumps, branches, twigs, needles, leaves, animal wastes and dead animals break down, they become unrecognizable as plants and animals and begin to resemble rich, fertile soil. No unpleasant smells, no intervention required. When human beings lived in small nomadic hunter-gatherer groups, solid waste disposal was not a problem. When more complex agricultural societies developed, man began producing significant quantities of waste. He also recognized the need to maintain the fertility of cultivated soil.

One of the earliest references to compost use appears on a set of clay tablets from the Akkadian Empire in the Mesopotamian Valley 1,000 years before Moses. The Romans knew about compost, the Greeks and the tribes of Israel both had a word for it. There are references to it in the Bible and Talmud. There are also references to composting in medieval church texts and Renaissance literature and the Chinese systematically applied the principles of composting. The "father of modern composting" is Sir Albert Howard, a British government agronomist. Sir Howard spent 29 years in India studying various scientific methods to make compost. His landmark book, *An Agricultural Testament* (1943), generated renewed interest in organic methods of agriculture and gardening. J. I. Rodale, in North America, carried Howard's work further. He established the Farming Research Centre and Organic Gardening magazine. Now, organic methods in gardening and farming are becoming increasingly popular. Even farmers who rely on chemical fertilizers recognize compost's value for plant growth and soil restoration. Today, farmers, gardeners and scientists continue to refine composting (ref. Hanson, *Easy Compost* p.11).

As our understanding of the biology of composting grows, we appreciate that Mother Nature is a far more elegant recycler than we.

What is composting?

Composting is a method of solid waste management whereby the ***organic component*** of the solid waste stream is ***biologically decomposed under controlled conditions*** to produce a ***valuable end product*** (Goldstein, ed., *Biocycle Guide to the Art & Science of Composting*, p.14).

Let's break down this definition.

What exactly is the "***organic component of the waste stream***"?

Organic refers to materials that were once living. Therefore, plant and yard wastes, wood and paper wastes, animal waste, manure and food scraps make up the organic component of the waste stream. As you will learn later, not all organic waste is appropriate for backyard composting.

What does the term "***biologically decomposed under controlled conditions***" mean?

Biologic decomposition refers to the breakdown of organic materials by bacteria, fungi and other ***living organisms***. In contrast, incineration is a non-biologic method of decomposition that breaks down wastes, but will not produce compost.

What do we mean by ***controlled conditions***?

Unlike the natural decomposition that "happens" on the forest floor, composting is a form of solid waste management. Composting systems can be manipulated to encourage specific organisms and discourage others. Yard waste composting is designed to encourage oxygen breathing microorganisms (primarily bacteria, fungi and actinomycetes) to dominate the system, whereas vermicomposting systems favor earthworms and anearobic sewage waste systems favor organisms that do not breathe oxygen. Even more specialized systems exist to handle specific wastes.

Finally, unlike wastes left rotting in an open garbage dump, composting produces a ***valuable end product***. That end product can be directly applied to the land as a beneficial ***soil amendment***.

What is compost?

Compost is defined by the Washington Organic Recycling Council (WORC) as ***"a product produced from the controlled decomposition* of *organic matter***". As we learned in Chapter 2, compost is basically ***man-made humus.*** As materials in the compost bin decay, they undergo the same biological and chemical transformations as natural organic litter. When we apply stable, mature, finished compost to the soil, it ultimately functions in the same manner as natural humus.

Compost Biology 101

Biologic decomposition is primarily the work of thousands of microscopic species of bacteria, fungi and a special group of organisms related to fungi called ***actinomycetes***. Microorganisms that feed on dead organic material are called ***saprophytes***. The ***saprophytic microbes*** can be divided into two basic groups, ***aerobes*** and ***anaerobes***.

Aerobes require oxygen to live. Aerobic, saprophytic bacteria, fungi and actinomycetes rapidly degrade organic matter and give off heat, water and carbon dioxide as by-products. Aerobic decomposition is odorless, therefore yard waste and vermicomposting systems are designed to encourage aerobic organisms.

Anaerobes do NOT require oxygen to live, in fact, oxygen is toxic to them. Anaerobic organisms are found in nature on swamp bottoms and in other oxygen-poor environments. They work slowly, produce no heat, and give off methane (sewer gas), hydrogen sulfide (rotten egg aroma), alcohols, phenols, terpines, putresines and cadaverines (their names suggest their offensive smells!). Many of the byproducts of anaerobes are toxic to earthworms, insects and plants. Anaerobes begin to function when oxygen concentrations drop below about 15%. When oxygen levels drop below approximately 8%, distinctive odors are generated.

Decomposition can occur by two basic processes, ***aerobic*** and ***anaerobic*.**

Aerobic decomposition requires oxygen.

Anaerobic decomposition occurs in the absence of oxygen.

Because aerobic organisms give off heat as a by-product of degradation, ***an aerobic yard waste compost pile gets hot during the most active phase of aerobic activity***. The internal temperature of an active compost pile can range from 0ºF to over 160ºF. ***This heat is totally independent of outside weather conditions and is solely the result of microbial activity***. No one species of bacteria, fungi or actinomycetes can survive this wide temperature range. Rather, each species is best adapted to a relatively narrow temperature range. Scientists classify species into three broad groups:

Psychrophiles: Microorganisms that thrive at temperatures ranging from 0ºF to 55ºF.

Mesophiles: Microbes that live in temperatures between 40ºF and 115ºF. The optimal range for many mesophiles is 90ºF to 115ºF. Actinomycetes and most fungi are mesophiles.

Thermophiles: Microorganisms adapted to temperatures ranging from 110ºF to 160ºF. Temperatures above 160ºF kill even the thermophiles and effectively sterilize the compost pile.

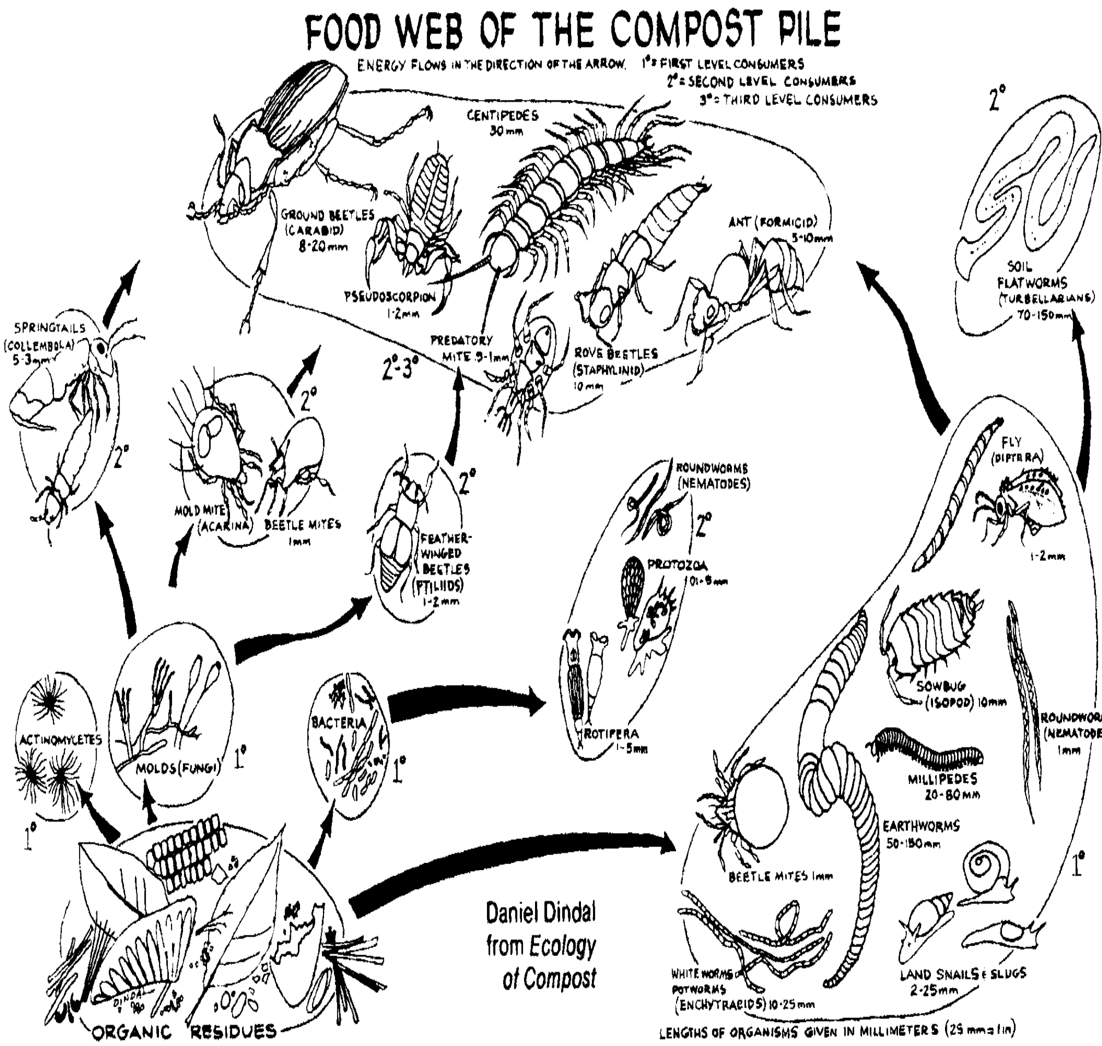
Yard waste compost systems are designed to encourage species from all three groups to be present at all times in a compost pile, ready to take advantage of whatever environment they encounter. Bacteria reproduce very rapidly; many have doubling times of 20 minutes or less. Under optimal conditions, in one hour 100 microbes divide to become 200, then 400, then 800, etc. Because every individual in this huge population gives off heat as it decomposes organic wastes, the pile gets hotter and hotter. The psychrophiles are replaced by the mesophiles who are replaced by the thermophiles. The microbes that die contribute organic matter to the compost pile. Their spores (seed-like reproductive bodies) generally survive high temperatures and will give rise to new individuals when the temperature cools sufficiently.

Compost Food Web

Microscopic bacteria, fungi and actinomycetes are the real workers in the compost pile, but they are just one part of a complex and fascinating ecosystem we call the "Compost Food Web"(see Figure 3*).* You may recognize Figure 3 as the Soil Food Web you studied in Chapter 2, and indeed it is the same figure. The same organisms that create natural humus are hard at work in the compost pile.

When we compost, we simply control the environment in such a way to encourage one or more groups of organisms.

Figure 3. Compost Food Web. From Dindal 1971, *Ecology of Compost*.



Primary layer:

Bacteria, fungi and actinomycetes are at the bottom or primary layer (1^o) of the Compost Food Web. These organisms feed directly on decomposing waste. Thousands of species of these organisms exist, and it is not fully understood which species are most active in the compost process. Nonetheless, they all feed on decaying organic matter by secreting ***enzymes***. Enzymes are specialized proteins that break down carbohydrates, proteins or fats into simple molecules that can be used as by the microorganism. These simple food molecules are then digested by the bacteria and fungi and utilized for building and maintaining cell structure, reproduction and energy. The only byproducts of this metabolic process are carbon dioxide (CO_2), water (H_2O), and heat. Bacteria do the lion's share of work in a compost pile. They are the primary degraders of organic waste. There are species of aerobic bacteria that thrive in all temperature ranges. Actinomycetes and most fungi are mesophilic. They generally appear on the outside layer of the pile as a gray or green powdery coating. Both actinomycetes and fungi are most active in degrading ***cellulose*** and ***lignins***, components of paper and woody materials (ref. Goldstein, ed. *Biocycle Guide to the Art & Science of Composting*, p.18).

Flies, sowbugs, pot worms*, *earthworms and ***snails*** can also feed directly on wastes, but unlike the microbes, they produce a "manure" that can be further metabolized. In addition, some also feed on bacteria, fungi and actinomycetes, thereby acting as both 1^o and 2^o consumers. Earthworms are sensitive to light, temperature and moisture and will only visit a compost pile that is dark, cool and moist. Although they play a role in backyard composting, they are not usually present in large numbers. Vermicomposting is controlled in such a way to encourage earthworms and discourage thermophillic bacteria. Vermicomposting systems do not go through a thermophillic stage (see Chapter 5).

Secondary layer:

Bacteria, fungi and actinomycetes have enemies lurking in the compost pile. They are fed upon by a group of organisms that comprise the second layer (2^o) of the food web. These organisms include:

Protozoa: Microscopic single cell organisms capable of self propelled movement that feed on bacteria. Protozoa help regulate bacterial populations and serve as a food source for organisms higher in the food web.

Nematodes or Roundworms*:* Microscopic, unsegmented worms with a long cylinder-shaped body. They feed on plants, bacteria, fungi and other nematodes.

Rotifers*:* Single cell organisms, usually found in water, that move using rings of tiny hairs on its front end and feed on bacteria.

Springtails **(Colembola)**: Tiny, white insects that feed on fungi.

Mites **(Acarina):** Arachnid (8 legged, spider-like) insects that feed on fungi.

Beetles: Large group of insects that feed on fungi.

Tertiary or Top layer:

The predators occupy the third and highest level of the Compost Food Web. These include:

Ground Beetles: Fairly large, feed on insects.

Pseudoscorpions: Rarely seen predator that feeds on insects.

Centipedes (Chilopoda): Fast moving, many legged predators that can bite humans and will eat beneficial worms. Not a welcome member of the compost pile.

Millipedes (Diploda): Round, hard-shelled, slow moving, many-legged beneficial vegetarian.

Ants: Many species, feed on insects.

Five Yard Waste Compost Control Factors

All the organisms in the Compost Food Web are necessary to completely degrade organic waste and produce finished compost. In nature, the process of decomposition is erratic, depending on temperature, moisture levels and the types of decaying materials. Unlike natural decomposition, compost is biologically decomposed under controlled conditions, and ***well-managed yard waste composting favors aerobic microorganisms***. It is our job as composters to create and maintain an environment that encourages these organisms to thrive 24 hours a day. The **Five Control Factors** summarized in Table 4 and described in detail below are the keys to optimal performance.

Control Factor 1: Aeration

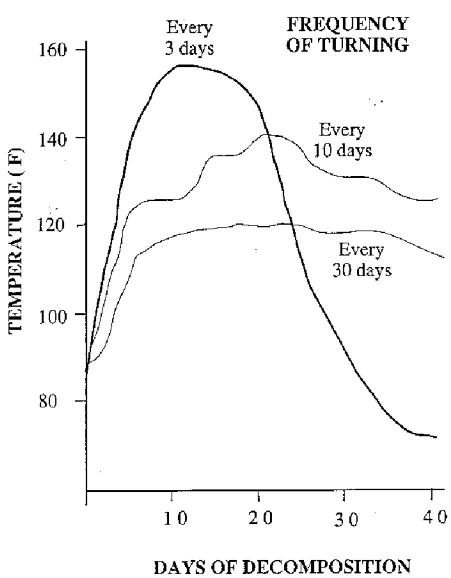
Aerobic decomposition cannot take place without oxygen! Remember both aerobes and anaerobes are present in the compost pile; their relative numbers depend solely on oxygen concentration. In the absence of oxygen, anaerobic organisms and their unpleasant odors will take over. Oxygen can penetrate passively about 18". Once the oxygen in the thermophilic center of the pile is depleted, the pile will cool off and the dormant anaerobes will repopulate the compost. How to maintain adequate oxygen and encourage aerobic organisms? Turn the pile! The graph in Figure 4 shows the effect of turning the pile on the rate of decomposition as measured by temperature change. As the graph illustrates, a pile turned

Table 4. **Optimizing Your Yard Waste Compost Pile.**

CONTROL FACTOR	IDEAL CONDITIONS
Aeration	Turn pile every 3 days.
Moisture	Moisture level 45 – 60%, consistency of wrung out sponge.
Volume	3' x 3' x 3' (One cubic yard)
Particle Size	1-2" diameter at largest point.
C:N Ratio (Carbon:Nitrogen)	30:1 C:N, Equal volume of "browns" and "greens".

every 3 days will decompose far more quickly than a pile turned every 10 or 30 days. If turning every 3 days is good, would turning the pile every day be better? NO! Fungi and actinomycetes are extremely sensitive to temperature and oxygen concentrations and thrive only in the cool, oxygen rich, outermost layer (4" to 6") of a compost pile. (ref. Goldstein, ed. *Biocycle Guide to the Art & Science of Composting* p.19). If a pile is turned too frequently, fungi and actinomycetes populations cannot reach critical mass and cellulose degradation suffers.

Figure 4. Frequency of Turning.



Control Factor 2: Moisture

Water is essential for all living organisms. The microorganisms in a compost system rely on water not only for their metabolic functions, but also as a medium through which they move to all parts of the pile. Many microbes can travel only through water. Moisture and aeration are closely related. Too little moisture cannot sustain microbial life and too much squeezes out oxygen and encourages proliferation of anaerobes. The ideal moisture level is ***45%–60%, the consistency of a wrung out sponge***. A handful of compost should feel moist but should produce no water drops when squeezed. When moisture levels exceed about 70%, water molecules fill the oxygen pores between particles and anaerobes are favored.

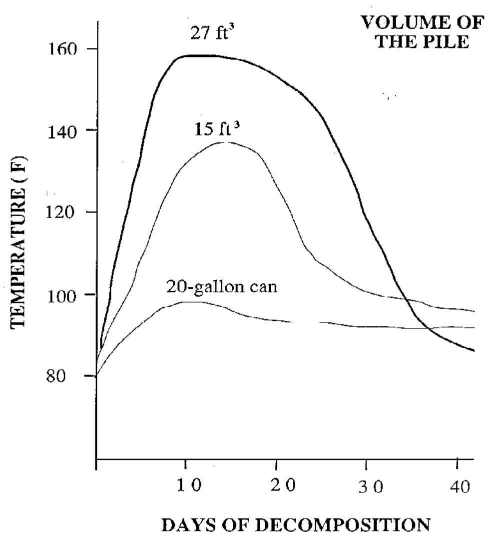
Control Factor 3: Volume

As you know, aerobic decomposition generates heat as a byproduct. As compost goes from the psychrophilic to mesophilic to thermophilic temperature range, the rate of decomposition increases. The most active breakdown occurs in the thermophilic range. An ideal compost pile must be well insulated to retain the heat generated by microbial action and encourage the proliferation of thermophilic organisms.

Figure 5 illustrates the effect of volume of a pile on the rate of decomposition. The most efficient volume for a home compost pile is 27ft^3 or ***one cubic yard*** One cubic yard is equivalent to a pile measuring 3ft high x 3ft wide x 3 ft deep and contains 6½ 32-gallon trashcans full of shredded organic material. As Figure 5 demonstrates, reducing the pile size to 15ft^3 or to 20 gallons dramatically reduces efficiency. The 15ft^3 pile barely makes it into the thermophilic range and the 20 gallon pile never gets hot.

Is a pile greater than 1 cubic yard more efficient? Yes and no. Commercial composters generally handle piles greatly exceeding 1 cubic yard. These piles have

Figure 5. Effect of volume.

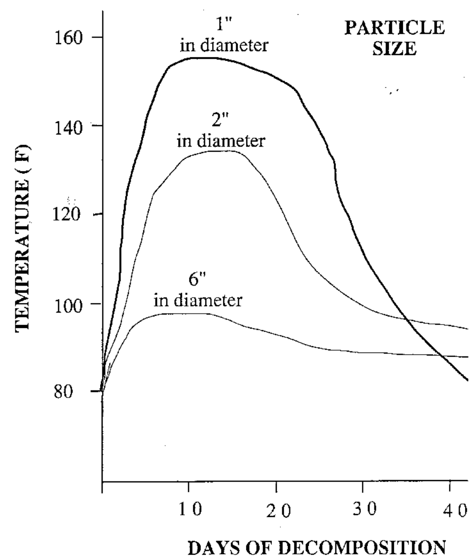


such huge mass that they often reach temperatures exceeding 160°F (sterilization temperature) and require vigilant monitoring to keep the beneficial organisms aerated and alive. Commercial operations use heavy machinery and many man-hours to move and turn the piles. For the homeowner, piles larger than 1 cubic yard become difficult to turn and aeration suffers. Like its commercial counterpart, a large home pile can become so hot that beneficial microbes will die. The largest manageable home compost pile is about 5ft x 5ft x 5ft. If a homeowner has large amounts of compostable materials, it is more prudent to advise several smaller piles rather than one big pile.

Control Factor 4: Particle Size

We have all witnessed the dramatic effect particle size has on the rate of organic decomposition. A tree stump may take 20 years to break down, while grass clippings are unrecognizable within 24 hours. The difference is due to the amount of ***surface area*** available to microscopic organisms at the bottom of the Compost Food Web; the more surface area available, the faster the rate of breakdown. In addition, most plants have a protective outer "skin" that naturally resists bacteria and fungi. Breaking or chipping the plant exposes the vulnerable inner surfaces to microbial action.

Figure 6. Effect of particle size.



As Figure 6 demonstrates, the ideal particle size is 1"-2" in diameter at the largest point. Particles smaller than 1" in diameter tend to compact more easily, squeezing out air molecules and fostering the proliferation of anaerobic organisms. An ideal system, in which all materials are 1"-2" in diameter, the pile heats quickly and evenly, reaching the thermophilic temperature range within 10 days. If particle size is increased to 6" in diameter, the pile never leaves the mesophilic range and degradation is slow. The simplest way to achieve ideal particle size is by running over the materials with a lawn mower, chopping them with a machete or by using a chipper/shredder. Shredded materials not only increase the rate of decomposition, a pile composed of uniformly sized organic materials has greater insulating value, sheds rainwater, resists excessive drying, and is easier to turn and harvest.

In practice, it is not necessary to achieve total uniformity. In fact, the addition of a few larger chunks of material (pine cones, small branches, etc.) may improve aeration by providing avenues for oxygen to move through the system. This is especially important when large amounts of grass (particle size less than 1") or very wet materials are added to the compost pile.

Control Factor 5: C:N Ratio

All living organisms require Carbon (C) and Nitrogen (N) to live. Carbon is used for both cell structure and energy while nitrogen is used primarily in building cell proteins. The relative concentrations of the two elements are expressed as the ***C:N Ratio*** (Carbon to Nitrogen Ratio). A material containing 10 times more C than N is said to have a C:N Ratio of 10:1. A material containing half as much C as N would have a C:N ratio of 0.5:1.

Cells need more carbon than nitrogen. In fact, ***most organisms use 30 parts of carbon to each part of nitrogen (C:N ration of 30:1).*** When the carbon and nitrogen content of a compost pile approaches a C:N of 30:1, it provides an ideal food source for compost organisms.

Table 5 lists the C:N Ratios of many commonly composted materials. These ratios were determined by chemical analysis. ***Nitrogen-rich*** materials have C:N ratios of

Table 5. C:N Ratio of Organic Waste Materials.
(adapted from Appendix A: On-Farm Composting Handbook, 1992, NRAES).

Material	**C:N Ratio**	**Brown or Green?**
Manure (Farm animals)	6-19:1	Green
Vegetable waste	11-19:1	Green
Hay	15-32:1	Green
Shrub/garden trimmings	16:1	Green
Grass Clippings	17:1	Green
Coffee Grounds	20:1	Green
Fruit waste	20-49:1	Green
Corn stalks	60-73:1	Brown
Dried leaves	40-80:1	Brown
Pine Needles	60-110:1	Brown
Straw	80:1	Brown
Saw dust	125-600:1	Brown
Newspaper	398-852:1	Brown
Bark dust	560-641:1	Brown
Cardboard	563:1	Brown
Chipped branches	~600:1	Brown

less than 50:1. Nitrogen-rich materials are referred to as "***greens***" because they are often (though not always) green or brightly colored. "Greens" tend to be soft-structured and rich in moisture. ***Carbon-rich*** materials have C:N ratios above 50:1. Carbon-rich materials are considered "***browns***". Browns often have a brown or golden color and tend to be dry, bulky and fibrous. If carbon content greatly exceeds nitrogen (high C:N, ratio greater than 50:1), bacteria will rapidly use all the available nitrogen and die. As they die, they release their cellular nitrogen, allowing another round of bacterial growth. Because nitrogen is limiting, each round of growth will be short and degradation will be very slow. If nitrogen concentrations are too high (low C:N, ratio less than 30:1), bacteria will release unused nitrogen as ammonia. In addition to its nasty aroma, ammonia is toxic to beneficial worms and insects. Compost high in soft structured, nitrogen-rich materials can squeeze out oxygen and encourage anaerobic organisms.

How do we blend our diverse organic wastes to achieve a C:N of 30:1 in our compost pile? http://www.compostinfo.com/cn/index.htm will let you build a virtual compost pile and get an idea how much of various materials are needed to keep a healthy and balanced compost pile. Otherwise, follow this simple rule of thumb: ***Mixing an equal volume of brown and green materials will result in a C:N of 30:1.*** In other words, for every shovel full of browns, add a shovel full of greens and mix well. No need to even dust off the old calculator!

To Turn or Not to Turn: "Passive" versus "Thermal" Compost

As Master Composters, we strive for the ideal, but most homeowners (and most of us!) don't want to dedicate themselves to composting. What happens to a neglected pile? Remember, COMPOST HAPPENS! Idealizing the 5 Control Factors will simply increase the ***rate of decomposition.*** An ideal "thermal" pile will produce finished compost in as little as 4-6 weeks, whereas a "passive" pile may take a year or more to complete the degradation process. A passive pile rarely reaches the thermophilic temperature range and most decomposition is carried out by psychrophilic and mesophilic micro-organisms. There is some evidence that passive compost can retain more nutrients than does thermal compost, but finished passive compost has no greater or lesser value than does finished thermal compost. One important difference exists. Many weed seeds and plant pathogens will not be destroyed unless they are exposed to temperatures in the thermophilic range. In fact, ***to kill weeds and pathogens, compost must reach 135ºF-160ºF for 6 hours/day for 3 consecutive days***. When the temperatures begin to drop after the third day, the pile must be turned and heat up to 135ºF–160ºF for 3 more days. After a second turning and 3-day heating cycle, most weeds and pathogens will be killed. It is virtually impossible for a home compost system to sustain temperatures hot enough to kill weeds and pathogens. Therefore, ***to avoid inoculating your garden with weeds or diseases, do not add weeds or diseased plants to a home compost pile.***

Materials that belong in a Yard Waste Compost Pile

For quick reference, see Table 6 for a summary of the following information.

Grass clippings

Excellent N source; mix well with browns to avoid compaction. May be better left on the lawn (see Chapter 7).

Spent flowers

N source.

Shredded fresh or dried deciduous leaves

Excellent source of C.

Moss

Moss will fully decompose. Finished compost from a moss-containing pile does NOT spread moss.

Shredded newsprint or cardboard

Probably better in the recycling bin, but can serve as a C source. Make sure to shred and spread well to avoid compaction.

Vegetable peels, wastes, coffee grounds

Excellent N source. Avoid any vegetable waste contaminated with grease or oil. Check particle size. May be better used in a Worm Bin (see Chapter 6).

Fruit peels, wastes

Bury well to avoid attracting fruit flies. May be better used in a Worm Bin (see Chapter 6).

Bread scraps

Avoid butter or margarine.

Farm animal manure

Excellent N source, may be odor problem. Mix well with browns.

Hair

Pet and human hair are good sources of N.

Shredded, dried broad-leaved evergreen leaves

These include rhododendron, azalea, laurel, holly, Oregon grape, and salal leaves. Drying and shredding will break down protective waxy cuticle and allow microbial access.

Shredded pine needles

Use in moderation, tough protective coat makes them slow to break down. Pine needles are acidic as they break down. May be more useful as mulch for acid-loving plants.

Straw

Good source of C, make sure to mix well and watch particle size.

Chipped branches

Use in moderation, slow to degrade. May be useful to create air channels.

Pinecones

A few pinecones are beneficial to create air channels, but they degrade very slowly.

Shredded natural fabrics

Cotton, wool, and silk scraps, if well shredded will decompose in a compost pile. Polyester, on the other hand, lasts forever!

Sod

Break up and shake off as much soil as possible before adding (large quantities require a specialized method of composting, see Chapter 4).

Materials that DO NOT belong in a Home Compost Pile

For quick reference, see Table 6 for a summary of the following information.

Meat and Dairy

Avoid all meat, bones and dairy products. In addition to being a favorite food source of Salmonella, they attract flies and vermin. Meats also tend to decompose anaerobically by putrefaction.

Weed Seeds and Diseased Plants

Home composting rarely achieves the temperatures necessary to kill weeds and plant pathogens. It is best to either compost these separately (see Chapter 4) or take them to a commercial or municipal composting company (see Appendix II, Resources).

Highly Invasive Weeds

These include our favorite blackberries, Morning glory, Quack grass, ivy and mint. These plants grow by rhizomes (root-like stems that give rise to new plants) and will not be reliably killed in a home compost system. These are best managed by taking them to a commercial or municipal composting company (see Appendix II, Resources).

Poisonous Plants

Toxins produced by plants such as Nightshade (cardio-toxic) are not reliably killed in a home compost system. Handle these plants with caution. Poisonous plants are best managed by taking them to a commercial or municipal composting company (see Appendix II, Resources).

Weed & Feed Type Products

Weed & Feed Products contain a toxic broad-leaf herbicide called ***Dicamba***. Dicamba degrades very slowly. If a Weed & Feed Product is applied to lawn grass, the grass must be cut *twice* after application and the clippings either left on the lawn (see Chapter 7), placed in a Waste Reduction pile (see Chapter 4) or bagged and taken to a commercial or municipal composting company (see Appendix II, Resources). Only the *third* and subsequent clippings are safe to add the compost pile.

Black walnut leaves, nuts

Leaves, nuts and roots of the **black walnut** contain a chemical called ***juglone***, a persistent herbicide that when present in finished compost can kill sensitive garden plants. **Black walnut** leaves can be added to a Waste Reduction Pile (see Chapter 4) where the toxin will eventually break down. English walnut leaves are not toxic and may be added to a home compost bin.

Pet Waste

The feces of cats, dogs, pot-bellied pigs and exotic birds can contain pathogens or parasites that are transmissible to humans. Dog feces may transmit hookworm, cat feces are a source of salmonella and toxoplasmosis, and bird droppings can carry salmonella or Chlamydia psittaci (causes a severe respiratory illness called psittacosis). None of these pathogens or parasites is reliably killed in a home compost system. Pet wastes can be composted separately (see Chapter 4).

Human Waste

Human waste must NEVER enter a home compost system. The disease potential is great.

Glossy paper

Some glossy magazine photos contain toxic heavy metals and are best added to the recycle bin.

Chemically treated wood

Creosote or chemically treated woods leach toxic chemicals into the compost pile that kill beneficial organisms. Best hauled to a company that handles wood waste (see Appendix II, Resources).

Wood Ash

Wood ash is a good source of calcium and potash, but it is very alkaline and will dramatically alter the acid-base balance (pH) of the compost pile, killing many organisms and slowing the rate of decomposition. Many plants benefit from a top dressing of wood ash. Contact a Master Gardener for specific uses.

Lime

Like wood ash, lime is very basic and will alter the pH of the pile and kill beneficial organisms. Lime is better used elsewhere in the garden.

Commercial Compost Starters, Activators or Fertilizers

Many composting books advise adding a commercial "Compost Starter" or "Activator" to increase the rate of decomposition. These products generally contain ammonium sulfate, which acts as a nitrogen source. Unlike organic nitrogen, ammonium sulfate releases a burst of nitrogen. So much nitrogen is available that microbes cannot use most of it and the excess is released as ammonia. Locally high concentrations of ammonia kill many microbes, worms and insects. In addition to being a waste of money, there is no sound biochemical reason to add compost starters, activators or fertilizers to a home compost pile. Mixing materials to give a 30:1 C:N ratio will facilitate healthy, sustained microbial activity, without wasting nitrogen or money.

Soil

Again, some composting "Bibles" recommended adding soil to compost to "inoculate" it with beneficial microbes. Inoculation is NOT necessary. The surfaces of all plants are covered with saprophytic microbes just waiting for the plant to die so they can get to work. In addition, air currents carry microbial spores, and worms and insects will find their way in. Large quantities of soil will make the pile heavy and may increase the potential for compaction.

Sand

There is absolutely no reason to add sand to a pile. Sand is an inert substance; it cannot be composted. Like soil, sand will add weight to the pile.

Oily or Greasy Food Wastes

Kitchen oils and greases may attract flies and vermin to the pile.

Fresh broad-leaved evergreen leaves

Rhododendrons, azaleas and other broad-leaved evergreen leaves have a thick, waxy cuticle, which breaks down very slowly. They will eventually degrade, but it is better to add dried, shredded leaves.

Table 6. Do and Do Not Compost.

 DO Compost	 Do NOT Compost
Grass clippings	Meat and Dairy
Spent flowers	Weed seeds/diseased plants
Shredded or dried leaves	Highly Invasive Weeds
Moss	Poisonous Plants
Shredded Newspaper/cardboard	Weed and Feed Products
Vegetable peels, coffee grounds	Black walnut leaves
Fruit peels, wastes	Pet waste
Bread scraps	Human waste
Farm animal manure	Glossy paper
Hair	Chemically treated wood
Shredded broad-leaf evergreens	Wood ash
Shredded pine needles	Lime
Straw	Compost starter/activator/fertilizer
Chipped branches	Soil
Pinecones	Sand
Shredded natural fabrics	Oily/Greasy kitchen waste
Sod	Fresh broad-leaf evergreens

Your Pot of Gold: FINISHED COMPOST

Let's follow the decomposition process in an ideal yard waste compost pile. We carefully mix equal volumes of browns and greens, resulting in one cubic yard of materials with a perfect 30:1 C:N ratio. All particles are 1''-2" in diameter, and moisture is adjusted to 45-60%. It's a lovely summer day, so we pull up a chair, stick our handy compost thermometer into the middle of the pile, and enjoy the unfolding process. Aerobic decomposition begins immediately. Our careful mixing ensures that oxygen is well distributed throughout the pile. Because the ambient temperature today is 70ºF, the psychrophiles are dormant and mesophilic microbes predominate. Our compost thermometer reads 70ºF. Within hours, the temperature begins to climb as the mesophiles are replaced by the thermophiles. By the third day, temperatures peak at about 160ºF and begin to cool down. We grab our pitchfork and turn the pile. The temperature drops to ambient immediately after turning, but, within hours, the temperature begins to climb again. We chart the temperature rise and turn the pile each time the temperature curve peaks and then drops. Each turn ensures that no particle escapes the thermophilic center of the pile. After about 6 weeks, we notice that the volume is reduced by half and our vigilant turning no longer results in a temperature rise. We recheck our 5 Control Factors; all are perfect. Fearing the worst, we gently lift a handful of compost and inhale. A sweet, earthy smell delights us. We can't recognize any of the original materials; everything looks like dark, rich, crumbly humus. EUREKA! SUCCESS! Our wastes have been converted to ***finished compost***.

What is finished compost?

Contrary to much folklore, **FINISHED COMPOST IS NOT EQUIVALENT TO CHEMICAL FERTILIZERS.** Compost acts like humus to affect the physical, chemical and biological properties of the soil. Finished compost acts as a repository for the ***slow release of plant nutrients*** in a form plants can use and as a ***breeding ground for beneficial bacteria, fungi, protozoa, nematodes, insects and earthworms***. In general, finished compost contains ***less than 2% nitrogen, phosphorus or potassium*** (ref. Miller, *Soils in our Environment*, p236). It has a C:N ratio ranging from 10:1 to 20:1 (ref. Goldstein, ed., *Biocycle Guide to the Art & Science of Composting* p.179). It is neither acid nor basic, with a nearly neutral pH of approximately 7.5.

Finished compost is a veritable gold mine of beneficial bacteria, fungi, protozoa and nematodes. Gardeners have known for centuries that compost helps plants fight diseases, and recent scientific research shows us how. Plants can be divided into two basic groups depending on their microbial requirements: ***bacterially dependent*** and ***fungally dependent***. Bacterially dependent plants like row crops, annual flowers and grasses need their roots covered by beneficial bacteria in order to utilize soil nitrogen and resist disease. Fungally dependent plants, like trees, berries and woody shrubs require fungus-coated roots. In nature, plants derive these microbes from organically rich soil. When the soil is depleted, the plant roots become susceptible to pathogenic bacteria or fungi. Leaves, too, must be covered in beneficial microorganisms to protect the plant from air borne pathogens. Amending the soil with finished compost or spraying the foliage with a microbe rich solution repopulates the roots and leaves with beneficial microbes and helps the plant fight disease.

Using Finished Compost

Using Finished Compost as a Soil Amendment in New Lawns and Beds

Poor soils are low in organic matter. The subsoil exposed during construction usually contains less than 1% organic material. To be effective, it is important to amend at least the top 6-8 inches of soil with sufficient compost so that the final soil contains between 8% and 13% organic material by soil weight. Professional landscapers test the soil before amendment and use fairly complex calculations to determine the correct amount of compost necessary to achieve 8-13% organic content. The homeowner can follow a simple rule of thumb: ***a 2 to 1 ratio of existing soil to compost, by loose volume will achieve the desired organics level***. Large quantities of compost may be necessary ***as one inch of compost spread over 1000 square feet is equivalent to approximately 3 cubic yards of compost*** (ref. Kolsti, Kyle F. et al.) Although a pick-axe works well in small areas, large areas will require mechanical tilling using a roto-tiller or even heavy tilling equipment. Usually, large projects require purchasing finished compost from a commercial source. It is important to ensure that the compost is free of viable weed seeds and diseased material.

Using Finished Compost in Established Beds and Lawns

To amend the soil in established flower or vegetable beds, gently work approximately ¼” compost into the soil around plants. Alternatively, simply top dress plants with compost; earthworms will carry it into the soil. For established lawns, the best time to amend the soil is during the spring or fall, after aeration. (For definition and more information, see Chapter 7). After aeration, spread a thin (approximately ¼”) layer of finished compost over the lawn and water well. The compost will slowly work its way into the soil as water and earthworms carry it down and plant roots push it around.

Using Finished Compost as Mulch

A 2” to 4” layer of finished compost makes wonderful mulch. In addition to looking attractive, preventing evaporation and suppressing weeds, finished compost mulch is a slow-release source of plant nutrients and beneficial microbes. Finished compost is far superior to bark dust as garden mulch. Bark dust is basically raw wood chips and fine sawdust particles. If a bark dust is too fine, it may actually restrict airflow to plant roots. In addition, because bark dust is raw wood with a very high C:N ratio, decomposing organisms may “rob” vital nitrogen from the soil to balance the bark dust’s high carbon content.

Using Finished Compost as Seed Germination/Potting Media

As you know, finished compost is not soil and cannot be used alone as seed germination or potting media. Finished compost is, however, a valuable soil amendment. To use compost as a potting media, it is important to sift it first to remove large (greater than ½” diameter) pieces. No more than ¼ to ⅓ of the total potting medium should be finished compost.

Finished Compost as a "Tea"

Compost tea is the water-extracted soluble fraction of finished compost (see also, Chapter 5). Gardeners and farmers have known the benefits of soaking seeds in or applying water extracts of compost to the soil and to plants for many years (ref: Rodale, *The Complete Book of Composting*). Modern research has validated their empiric insight by experimentally proving that **compost teas suppress plant diseases.** The information in this section is derived from a recently published comprehensive review of the scientific data available for compost tea (ref. Scheuerell, S.J. and W.F. Mahafee. 2002. Literature Review: Compost tea: Principles and Prospects for Plant Disease Control. *Compost Science & Utilization.* Autumn 2002; 10,4:313-338).

Compost teas can be divided into two general types: Nonaerated compost tea (NCT) and aerated compost tea (ACT).

Nonaerated Compost Tea: NCT refers to compost teas made by methods that do not disturb or only minimally disturb the fermentation after the initial mixing. Typically, NCT is made by mixing finished compost in a 1:5 – 1:10 (v:v) ratio of compost to water and then allowing that mixture to ferment in an open container at room temperature without stirring.

Aerated Compost Tea: ACT is made by methods in which the water is actively aerated during the fermentation process.

Methods for Producing & Applying Compost Teas: Making compost tea of any type requires a fermentation vessel, compost, water, incubation and filtration. Sometimes specific nutrients or isolated microbes are added to the mixture before, during or after fermentation. After fermentation, compost teas can be used undiluted or diluted. Teas are typically applied using a sprayer and most are filtered to remove large particles that would clog the nozzle before they are added to the sprayer. Sometimes chemical spray adjuvants are added to the tea to increase its ability to stick to plant surfaces.

How does Compost Tea Work? Research into the modes of action of compost tea is in its infancy. Comparing scientific results is especially difficult because factors such as the type of compost feedstock, the age of the compost feedstock, the compost to water ratio, the fermentation time, the addition of and nature of nutrients during fermentation, the fermentation temperature and pH all affect the composition of the compost tea. Most of the research has been done with NCT and **all the studies indicate that many modes of action are involved.** It is not known if ACT works by the same mechanisms.

The total microbial population of NCT is correlated to increased disease suppression. This is a key point. A vibrant, diverse, living microbial community is vital to disease suppression.

Compost tea can induce natural plant defenses: In other words, compost tea stimulates the plant to "fight a better battle".

Compost tea contains antibiotic-like molecules that suppress the growth of disease organisms. Research using heat sterilized or ultra-filtered NCT shows that an active heat stable, non-protein metabolite that acts like a plant antibiotic is either produced by the microorganisms during fermentation or was present in the compost used to make the tea.

Compost tea can act by competition. When applied to plant surfaces, the beneficial organisms in compost tea may successfully compete for nutrients or space, driving the disease organisms away.

Compost Tea Recommendations to the Public: Several businesses are making and selling compost tea to the public. As Master Composter/Recyclers, we may be asked for recommendations. It is important to understand that the science of compost tea is in its infancy. Many factors may affect the quality or suitability of a specific batch of compost tea. A**t the present time there are no standards for determining the suitability of a compost tea for a particular use.**

In addition, although unlikely, it is possible that human pathogens can be transferred from contaminated compost into the tea made from that compost. As a precautionary measure, we should advise the public to ask a commercial producer if the compost used for compost tea was tested for human pathogens.

C. Tricks of the Trade: Troubleshooting a Yard Waste Compost Pile

The following are some common questions you may encounter when dealing with the public.

Q: I don't garden. Why do I need a compost pile?

A: Composting has its own rewards. You are doing your part to keep organic waste out of landfills and to hold the line on increased waste disposal costs. You can give your finished compost away to a lucky gardener and make a friend for life. Even if you NEVER use your compost, it will eventually work its way into the soil as burrowing earthworms carry the rich organic matter into the surrounding ground.

Q: I don't have anything to compost, why should I do it?

A: Remember, coffee grounds, vegetable and fruit scraps and houseplant clippings are compostable. Also, consider helping neighbors and friends by composting some of their excess garden waste.

Q: I live in an apartment or condo with virtually no yard. Can I still compost?

A: Absolutely! Vermicomposting can be done ANYWHERE! (For details, see Chapters 5 and 6).

Q: With all this talk about bacteria and fungi, is there any danger in handling a compost pile?

A: Although some fungi pose a theoretical risk to immunosuppressed AIDS or cancer patients, there have been no reports of disease due to compost. The best prevention is the simplest: WASH YOUR HANDS WITH SOAP after handling compost.

Q: Help, I haven't turned my pile in a while and it's beginning to smell.

A: In the absence of adequate oxygen, anaerobes and their nasty byproducts have taken over your pile! Luckily, it's easy to fix by turning the pile to introduce more oxygen. Turn the pile until it reaches the thermophilic range (110ºF –160ºF) and all offensive odors are gone.

Q: **What is the best time of year to start a compost pile?**

A: Browns are abundant in the fall, greens in the spring. A good suggestion is to collect and store browns in the fall (make sure to keep them dry), and use them to start a pile in the spring. Alternatively, shredded paper or straw can be obtained year round as a substitute for fall leaves.

Q: Do I need to buy a chipper/shredder?

A: NO! Gas powered chippers are noisy, dangerous and polluting. Unless you have vast quantities of materials, manual methods are preferable

Q: If I keep adding fresh material to my compost pile, it will never be finished. Do I need two piles?

A: No, the next time you turn your pile, simply remove the finished compost and return the unfinished material to the pile. You can also build a 3-bin system, wherein most of the finished compost will be in the 3rd section (see Chapter 4).

Chapter 4

Yard Waste Compost Bins & Systems

A. Objectives

1. To become familiar enough with various composting systems to advise a prospective composter.
2. What is a Waste Reduction Pile and to whom would you recommend one?
3. To understand special situations such as sod and pet waste composting.

<u>Terms Defined in this Chapter:</u>

Chicken Wire Bin
Concrete Block Bin
Earth Machine
Open Pile
Seattle Composter
Sheet Composting
Three Bin Turning Unit
Urban Compost Tumbler
Waste Reduction Pile
Windrow
Wooden Pallet Bin

B. Study Materials

Helping People Choose the Right System

Many people come to Master Composter/ Recyclers for advice on how to start backyard composting. Before recommending a system, you may want to ask:

- What materials do you have or want to compost?
- How much space do you have in your yard for a compost pile?
- How much time do you want to spend working with your compost?
- What aesthetic criteria do you have? Does it have to look attractive or just be functional?
- How much time and money would you be willing to invest in a bin?
- How quickly do you want finished compost?

Armed with the answers to these questions, you can guide each individual to the system best suited to his or her needs. Remember, a happy composter is a lifelong composter!

Best Location for a Compost Pile

Responsible backyard composting requires consideration of others. Although a well-managed compost pile will not emit nasty odors, it is best to build the compost pile in a visually secluded area downwind of neighbors. This advice is most applicable to large, open, unconfined piles; most commercially available home compost systems are designed to be relatively small and attractive. It is also important to build the compost pile near the source of waste materials and in a spot convenient to the user.

Social considerations aside, weather dictates the best location for a compost pile. In the Columbia Basin, the winters are cold and dry, and the summers are hot and dry. Locating the pile in an area that receives morning sun and afternoon shade is probably the best advice. Having a convenient source of water is also important. It is also best to avoid excessively windy areas because too much air circulation could dry the pile. Selecting a spot with good drainage will prevent the area around the compost bin from becoming a muddy mess in wet weather. Some composting books recommend placing a pile under a tree. Be aware of the species of tree, avoiding black walnuts, pines and bay laurels (ref. Harmonious Tech., *Backyard Composting*, p.25). You can add to your pile during the winter, but it won't do much until spring.

Tools and Gadgets

Few tools are truly required for composting. A sturdy pitchfork and wheelbarrow will serve the average composter for decades. Handy additions include a mulching lawn mower, blower-vac or machete to shred materials. Although a minimalist can get by with an old shovel, the "compostophile" may invest in a host of specialized tools including compost thermometers, compost turners, and compost sifters (see Figure 7).

Sheet Composting

Sheet composting is unique in that there is no compost pile. Mixed organic wastes are worked into the soil by physically tilling them in. Decomposition takes place naturally in the soil. Sheet composting is usually used in large cultivated gardens. Materials are manually or mechanically tilled into the soil in the fall and left to decompose until the spring planting season. It is important to give the tilled organic matter enough time to fully decompose before planting. Microorganisms and plants both require nitrogen, and the microorganisms will out-compete the plants and "rob the soil" while actively breaking down wastes. If organic material is tilled into the soil early enough in the spring, enough of it will have decomposed to allow planting four to five weeks later (ref. Putnam, *Ortho Books: Easy Composting*, p.56).

A variation of this technique involves rotating trenches. In the first growing season, seeds are planted in alternating rows, separated by rows of tilled-in decomposing organic materials. In the next season, planting rows and decomposing organic matter rows are reversed. For an avid gardener, this method produces rich, fertile soil season after season.

Open Pile or Windrow

An open pile is simply unconfined compost. Open piles generally require a significant amount of space and distance from neighbors. They can be actively managed to produce compost quickly or left to decay naturally. Open piles should measure approximately 3ft x 3ft x 3ft (1 cubic yard) for peak efficiency.

Simple Homemade Enclosures and Bins

Figure 7 illustrates many systems and the advantages and disadvantages of each system are summarized in Table 7.

- **Wire or plastic mesh enclosure**

  Wire and plastic mesh are inexpensive and readily available and can be used to form a simple circular enclosure of any diameter. They are easy to open or disassemble when the compost needs turning, but unfortunately, both materials are flimsy and tend to distort easily and tip. In addition, unless the bins are covered they are prone to rain or excessive dryness, inquisitive pets, birds and rodents. ***Wire or plastic mesh enclosures may be best suited as a corral to stockpile browns in the fall.***

- **Wooden pallet bin**

  Wooden pallets are readily available and can be assembled into an almost perfect cubic yard bin by nailing or wiring the sides together. With a bit more work, one can make one side a "hinged" door for easy access when turning or harvesting. Placing a pallet on the bottom of the cube helps provide aeration. Unfortunately, pallet bins are heavy, unattractive, and prone to decay.

- **Concrete block bin**

  Concrete blocks offer a modular approach to compost bin building. They can be used to build a single or multi-bin unit. Concrete blocks are relatively inexpensive, and their design allows good ventilation. Generally, concrete bin systems require a lot of space and are heavy and difficult to move.

Homemade Three Bin Turning Unit

The Three Bin Turning Unit is attractive and can handle a large amount of waste, but it requires a bit of woodworking skill to build. Construction plans are available free through the Master Composter/Recycler Program.

In this system, mixed, organic waste is added to the first bin. After the first heating cycle, the partially composted materials in the first bin are turned into the second bin and fresh wastes are added to the first. The fresh materials in Bin 1 and the newly turned materials in the second bin will go through a second heating cycle. At that time, the material from Bin 2 is turned into Bin 3, material from Bin 1 moves to Bin 2 and fresh waste is added to Bin 1. When the compost in Bin 3 is finished, it is removed for use and the cycle starts again.

Commercially Available Compost Bins

Many commercially produced compost bins are advertised to the public. A few of the locally available systems are considered in detail below.

Every system has advantages and disadvantages (see Table 7). Although we currently recommend the Seattle Composter, other systems are in common use and you may be asked for advice.

Figure 7. Compost Bins & Systems.

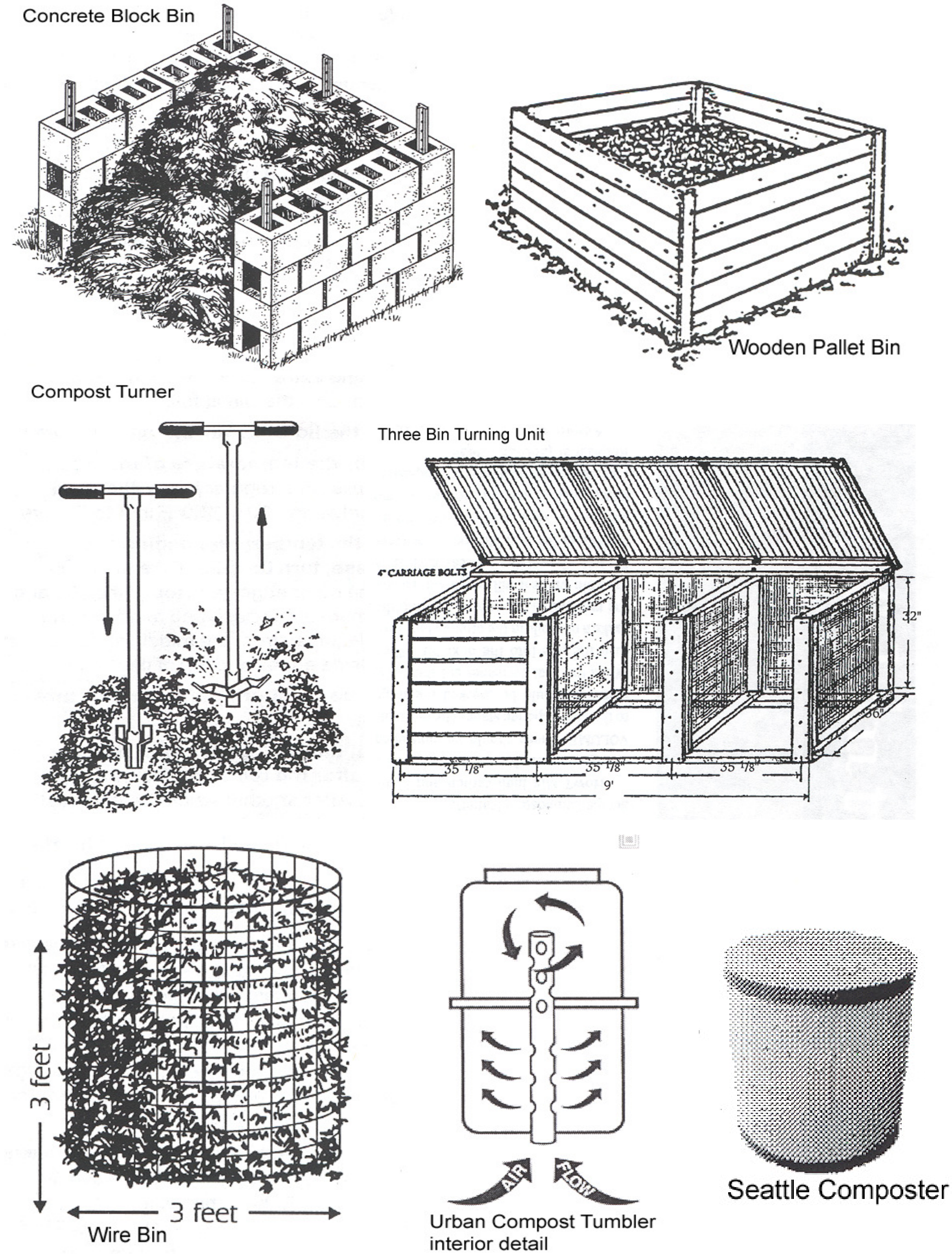


Table 7. Compost Bins & Systems: Advantages and Disadvantages.

Bin or System	Advantages	Disadvantages
Sheet Composting	1. No pile required.	1. Materials must be tilled into soil. 2. Must wait to plant in newly tilled areas.
Open Pile or Windrow	1. Simple, no container. 2. Good for large quantities.	1. Requires significant space. 2. Pile spreads, untidy.
Chicken wire or plastic mesh	1. Inexpensive or free. 2. Simple to make. 3. Can be built to any diameter. 4. Easy to disassemble for turning or harvesting. 5. Great system to stockpile browns in the fall.	1. Flimsy, prone to distortion and tipping. 2. Unattractive. 3. No cover, susceptible to weather. 4. Vulnerable to rodent and other pests.
Wooden Pallet Bin	1. Free or inexpensive; pallets are a good use of recycled materials. 2. Easy to make. 3. Can make one side a “hinged” door for easy access. 4. Pallet cube is almost a perfect cubic yard.	1. Unattractive. 2. If uncovered, it is susceptible to weather. 3. Vulnerable to rodent and other pests. 4. Heavy, difficult to move.
Three Bin Compost System	1. Attractive, relatively easy to build. 2. Free construction plans. 3. Each compartment 1 cubic yard. 4. Easy to turn compost. 5. Covered, protected from weather.	1. Requires woodworking skill. 2. Requires large area. 3. Heavy, difficult to move. 4. Wood will eventually decompose.
Seattle Composter	1. Neat, affordable through MC/R. 2. Made of recycled materials. 3. Easy to assemble, disassemble. 4. Covered top and bottom.	1. Small volume.
Earth Machine	1. Neat. 2. Made of recycled materials. 3. Easy to assemble. 4. Inaccessible to rodents, pests.	1. Relatively expensive. 2. Small volume. 3. Hard to turn compost. 4. Sliding door difficult to operate.
Urban Compost Tumbler	1. Neat. 2. Made of recycled materials. 3. Easy to turn. 4. Produces finished compost rapidly. 5. Inaccessible to rodents, pests.	1. Relatively expensive. 2. Small volume. 3. Must be set on solid, level surface. It may tip. 4. We do not recommend manufacturer’s suggestions.

- **Seattle Composter**

  The Seattle Composter is made by Recycled Plastics Marketing, Redmond, WA (See Appendix II, Resources). It is a simple, attractive 100% recycled green plastic cylinder with black top and bottom lids. The Seattle Composter is fully guaranteed by the manufacturer against breakage. The Seattle Composter holds 12 cubic feet of material. Although the Seattle Composter is relatively small, it is a good system for urban and suburban homeowners.

- **Earth Machine**

  The Earth Machine is made by Creative Energy Technologies, Summit, NY (see Appendix II, Resources). It is a black plastic inverted cone (34" at base, 33" tall) made of 50% recycled plastic. It holds 11 cubic feet of material, has air vents and a sliding door at the bottom. The Earth Machine is guaranteed for 10 years. Misconceptions about this system abound. First, the black color DOES NOT cause the compost to heat up! As you know, compost heat is totally independent of outside weather conditions and is *solely* the result of microbial activity. Second, well-seasoned, finished compost is unlikely to pour from the convenient sliding door at the bottom of the Earth Machine. The *center* of the compost pile is the most active; materials from the outside edges will degrade more slowly. Therefore, unless the contents are turned frequently, materials harvested from the sliding door will tend to be incompletely decomposed.

- **Compost Tumblers**

  The **Urban Compost Tumbler** is an innovative design by Portland-based, D&P Industries, Inc. It is basically a 95% recycled plastic food grade barrel with an aeration tube running through its center that is mounted on a stand. (See Appendix II). Although this system provides finished compost quickly, it is relatively expensive and 55 gallons is rather small. In addition, we do not recommend some of the manufacturer's composting suggestions.

Specialized Systems

- **Waste Reduction Pile**

  A Waste Reduction Pile is simply a separate compost pile dedicated to decomposing undesirables like black walnut leaves, pesticide or herbicide treated plants, and some weeds and diseased plants. Although the main purpose of a Waste Reduction Pile is to keep organic material out of the solid waste stream, finished compost from this pile may be used as a mulch or soil amendment in areas where weeds or diseases are not a concern. Finished compost from a Waste Reduction Pile should not be used in a vegetable garden or near sensitive plants.

- **Deep Pit Composting**

  Meat scraps and pet waste can be buried under the drip line of ORNAMENTAL plants, shrubs and trees. Dig a hole at least 1 foot deep, put 3 to 4 inches of meat scraps or pet waste at the bottom of the pile and cover with soil. ***NEVER BURY MEAT SCRAPS OR PET WASTE IN***

AREAS WHERE FOOD WILL BE GROWN.

- **Sod**

  Small amounts of sod can be shredded and added to a home compost pile. Large quantities of sod should be cut into strips, stacked grass-side down in a neat pile and then covered with black plastic. Build your sod pile in a place that will remain undisturbed for one to three years. As you stack, moisten each layer with a little water. When the sod is fully composted, you'll be left with high quality sod loam compost.

C. Tricks of the Trade: Which system is best?

Q: How do I decide on the best compost system?

A: The most important consideration is "What materials are you planning to compost?" Second, "How much compostable material do you think you will generate in a season?" Armed with the answers to those two questions, consider price, convenience and attractiveness when considering alternatives.

Q: I've got so many leaves that I can't compost them all. What should I do with the excess?

A: Dried leaves make excellent mulch. In addition, your neighbors may appreciate a bag of "browns". Another excellent alternative is taking your yard wastes to a local compost facility. Often, these facilities offer free leaf disposal during the fall season. Call for rates (see Appendix II, Resources).

Q: I have a large yard. When I add my grass clippings to the compost pile, it gets slimy and begins to smell. What should I do?

A: The answer is two-fold. Grass has a high moisture content and a soft structure, making it prone to anaerobic decomposition. Leaving the clippings on the lawn has many benefits (see Chapter 7). If you wish to compost clippings, make sure to mix them with an equal volume of those dried "browns" you stockpiled last fall or with straw or shredded paper. Grass is a great nitrogen source, and when properly mixed, will rapidly decompose without odor.

Q: My finished compost does not look like the bagged variety from the hardware store or nursery. What is the difference?

A: Commercial composts are usually screened before bagging. Screening assures uniform size. Although your irregularly sized compost is fine for most purposes, you can make a simple compost screen by stretching machine cloth (available at home centers) over a 2" x 4" wooden frame. Alternatively, you can buy a compost screen.

Chapter 5

Biology and Fundamentals of Vermicomposting

A. Objectives

1. Define vermicomposting and describe its important role in waste reduction.
2. Understand how vermicomposting differs from backyard composting.
3. Understand basic worm biology.
4. Define the qualities of composting worms, particularly *E. fetida.*
5. Understand the difference between finished backyard compost and vermicompost and become familiar with using vermicompost.

Terms Defined in this Chapter:

Anecic
Castings
Clitellum
Cocoon
Coelomic fluid
Crop
Dorsal vessel
Eisenia fetida
Endogeic
Epigeic
Gizzard
Hermaphrodite
Invertebrate
N-P-K
Pharynx
Photophobic
Prostomium
Pseudoheart
Setae
Ventral vessel
Vermicompost
Vermicompost Tea
Vermicomposting

B. Study Materials

(Please note: Much of the information contained in this and the following chapter is derived from M. Appelhof's excellent book, *Worms Eat My Garbage* and from *Worm Digests* No. 19 and No. 23. Please refer to these wonderful resources to supplement your training.)

What is Vermicomposting?

The term "***vermicomposting***" comes from the Latin "vermis" meaning worm and refers to the ***controlled degradation of organic matter primarily by earthworm consumption.***

Although commercial vermicomposting systems can be specialized to remediate virtually any organic material, home systems are designed to handle food waste. **Home vermicomposting systems** generally use one earthworm species, ***Eisenia fetida*** (pronounced "i SEE nee a FET id a"), and its associated organisms to ***break down organic waste into material containing nutrients for***

plant growth (ref. Appelhof, *Worms Eat My Garbage,* p.148).

Why Vermicompost?

As Master Composter/Recyclers our mission is waste reduction. Grant County buries more than 17,100 tons of food waste per year, and at 19%, food was the single largest component of the 2008 solid waste stream. Food waste burdens more than our landfills. Food that is ground in a garbage disposal and flushed into our sewers wastes water and places a significant burden on our water treatment plants. Even more importantly, ***food wastes are a valuable organic resource***. Plants grown with vermicompost require fewer chemical fertilizers and are more pest and disease resistant. Like backyard composting and recycling, vermicomposting is a method of converting a problem into a solution.

How does Vermicomposting differ from Yard Waste Composting?

If we can add food wastes to our backyard bins, why vermicompost? Composting, as you recall, is a method of solid waste management whereby the organic component of the solid waste stream is biologically decomposed under controlled conditions to produce a valuable end product. Yard waste composting is designed to encourage microorganisms (mainly bacteria, fungi and actinomycetes) to dominate the system and a well managed pile passes through a bacterially intense thermophilic phase. Vermicomposting, in contrast, is controlled in such a way to encourage many more earthworms than would be found in a yard waste system. ***The joint action of worms and mesophilic microorganisms decomposes organic matter and vermicomposting does not involve a thermophilic phase***. Because the dominant organisms differ, there are differences in the end products produced. Vermicomposting produces a unique end product that, as you will learn, is truly "Gardener's Gold".

In addition to their chemical and biological differences, composting and vermicomposting systems are managed differently, and vermicomposting has many unique advantages. Table 8 highlights some of the key advantages of vermicomposting. Many people use both systems and find that, although they are different, they are equally valuable.

"Vermi-terminology" 101

Becoming a Master Composter/Recycler has many benefits, not the least of which is having a great excuse to toss around Latin phrases. In addition to making us seem worldly and erudite, learning and using the scientific names of the worms avoids confusion. Common names abound and the same worm may have more than 10 names or three different species may share one name. The composting worm, ***Eisenia fetida,*** is commonly called a redworm, red wiggler, manure worm, red hybrid, fish worm, dung worm, striped worm, tiger worm and apple pomace worm (ref. Appelhof, *Worms Eat My Garbage,* p.38). Since successful vermicomposting requires using the correct worm species, it is important that we learn and teach the scientific names and terms.

As you may recall, scientists classify all living organisms into **kingdom, phylum, class, order, family, genus and species**. Color, size, external body structure, internal structure, preferred environment, feeding and reproduction patterns are all clues to classification. Most organisms are referred to by their genus and species names, wherein the name is italicized, the genus is always capitalized and the species is lowercase (example: Human beings=***Homo sapiens***). Genus and species names are often abbreviated by using just the first letter of the genus name followed by a period and the full species name, for example *Homo sapiens* is abbreviated to *H. sapiens*.

All worms belong to the **Kingdom Animalia (animal)** and the **Phylum Annelida (segmented).** Earthworms belong to the **Class Oligochaetae** while their relatives the aquatic worms and leeches are in a different class. We will focus on the most familiar **Family** of worms, the **Lumbricidae.** The Lumbricidae family includes the common nightcrawler, ***Lumbricus*** *(genus)* ***terrestris*** *(species)* and the two most common vermicomposting worms, ***Eisenia fetida*** and

Table 8. Advantages of Vermicomposting.

Consideration	Backyard Composting	Vermi-composting	"Vermi-Comment"
Size	Relatively large pile or bin required.	Small space requirement.	Great for condo, apartment dwellers.
Location	Outdoors only.	Indoors, Garage, Basement, Outdoors.	Very flexible.
Maintenance	Frequent turning and moisture adjustments necessary.	No turning, worms do the work. Rarely needs a moisture adjustment.	Easy for anyone! Little or no physical labor involved.
Predominant Organisms	Bacteria, fungi.	Redworms, bacteria, fungi.	Worm bin conditions favor high worm populations.
End Product	Finished compost is considered a soil amendment.	Vermicompost is considered plant food.	Vermicompost is a significant source of bio-available plant nutrients and beneficial microbes.
Entertainment Potential	Lots of interesting insects to see under a magnifying glass—will keep kids busy for at least 15 minutes.	KIDS LOVE WORMS. Worms and their worm-bin friends are a guaranteed hit! Fishermen will enjoy a captive source of bait, too.	Both systems can be fun and educational. Turn off the TV and get out a magnifying glass.

Eisenia andrei. Another family, the **Megascolecidae** is a huge family that includes a few less common species used for vermicomposting.

Worm Biology 101

We are all familiar with the soft, tubular invertebrates we call worms. More than 7000 land-dwelling earthworm species inhabit the earth (ref. Edwards, *Soil Biol Primer*, p.H-1). There are species adapted to nearly every soil type and climate, but only a few worm species are used in a vermicomposting. In order to understand why, we must first review a bit of basic worm biology.

All earthworms are ***invertebrates*** (have no backbone), breath oxygen, are ***photophobic*** (shun light), require high moisture levels and are ***hermaphrodites*** (have both male and female reproductive organs). Each earthworm species has specific characteristics that differentiate it, but all earthworms share the same fundamental physiology. Figure 8 illustrates the general features of an earthworm. The most important characteristics are discussed in detail below.

External characteristics of earthworms

- **Color**
  Worms range from colorless to deeply pigmented. Pigment can be present only on the top (dorsal) surface or bottom (ventral) surface of the worm or cover the entire worm. Worms may be solid colored, striped or patterned. Pigment colors and patterns vary with species.

- **Size**
  Earthworms range from nearly microscopic to 4 feet in length! Yes, there is an Australian worm that is FOUR FEET LONG. Length and diameter varies with species.

- **Body Segments**
  Body segments are the circular bands that characterize all ***annelids*** (segmented worms). The number of segments varies with species.

- **Mouth/prostomium**
  Worms have no eyes and no teeth. Only foods that have been rotted by bacteria and protozoa are soft enough to be taken into the worm's mouth. A flap called the ***prostomium*** plugs the mouth opening as the worm moves and pushes food into the worm's crop during feeding. The prostomium is covered with chemical receptors that act like eyes to sense food and the slime trails of other worms.

- **Skin**
  A worm's skin is like an external lung. It is covered in a mucous layer that dissolves atmospheric oxygen and transfers it to capillaries and blood vessels inside the body. Like us, worm blood contains hemoglobin that carries oxygen to the tissues.

- **Sensory Organs**
  Worms do not have eyes, but do have light sensitive organs in several places on the surface of their bodies. The most sensitive is on the front of the body near the prostomium. All worms are sensitive to light (photophobic) and excessive exposure will lead to paralysis and death.

  Worms also have sensitive nerves spread throughout their bodies that react violently to touch.

Because birds, moles and other worm predators create soil vibrations as they hunt, all worms are sensitive to vibration. Vibration causes a panic attack and worms will try to escape to an area free of vibration.

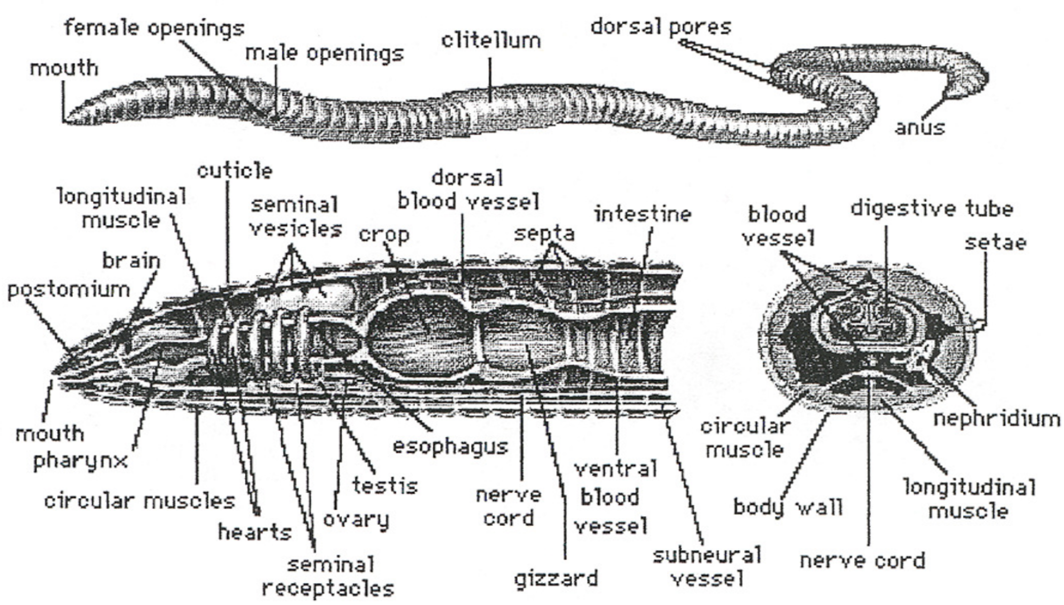
- **Clitellum**
  Earthworms are born sexually immature, and the time to maturity varies with each species. One can identify a mature worm by the presence of a thick band or "saddle" called the ***clitellum*** that encircles the worm. Depending on the species, the clitellum may be toward the mouth end, in the middle or toward the anus end of the worm.

- **Setae and Locomotion**
  Setae are a worm's "legs". Setae are tiny bristle-like structures that are arranged along the length of the worm. Setae can be arranged in various patterns either only on the ventral (bottom) surface of the worm's body or go all around. The pattern of setae arrangements is one of the criteria scientists use to differentiate various worm species. A worm moves by planting the setae on the rear segments of its body in the soil to anchor itself. It then constricts the muscles that circle its body, causing the body to bulge forward and extend the worm's front end. The worm then plants the setae on the front segments of its body to hold it in place and releases the rear setae while constricting the long muscle running the length of the body to pull its back end forward.

Internal characteristics of earthworms

- **Coelomic fluid**
  Worms have no bones or cartilage. Their structure is due solely to the hydrostatic

Figure 8. General Features of Earthworms. (from Edwards, *Biology and Ecology of Earthworms).*



pressure of the thick ***coelomic fluid*** that fills the body cavity.

- **Blood Vessels and Hearts**
  There are three principal blood vessels in a worm's body: the ***dorsal vessel***, which runs above the alimentary canal, and the two ***ventral vessels***, which run along the bottom side of the worm. Worms have five "***pseudohearts***", which are really no more than valved enlargements of the blood vessels that move blood from the dorsal blood vessel to the ventral blood vessels.

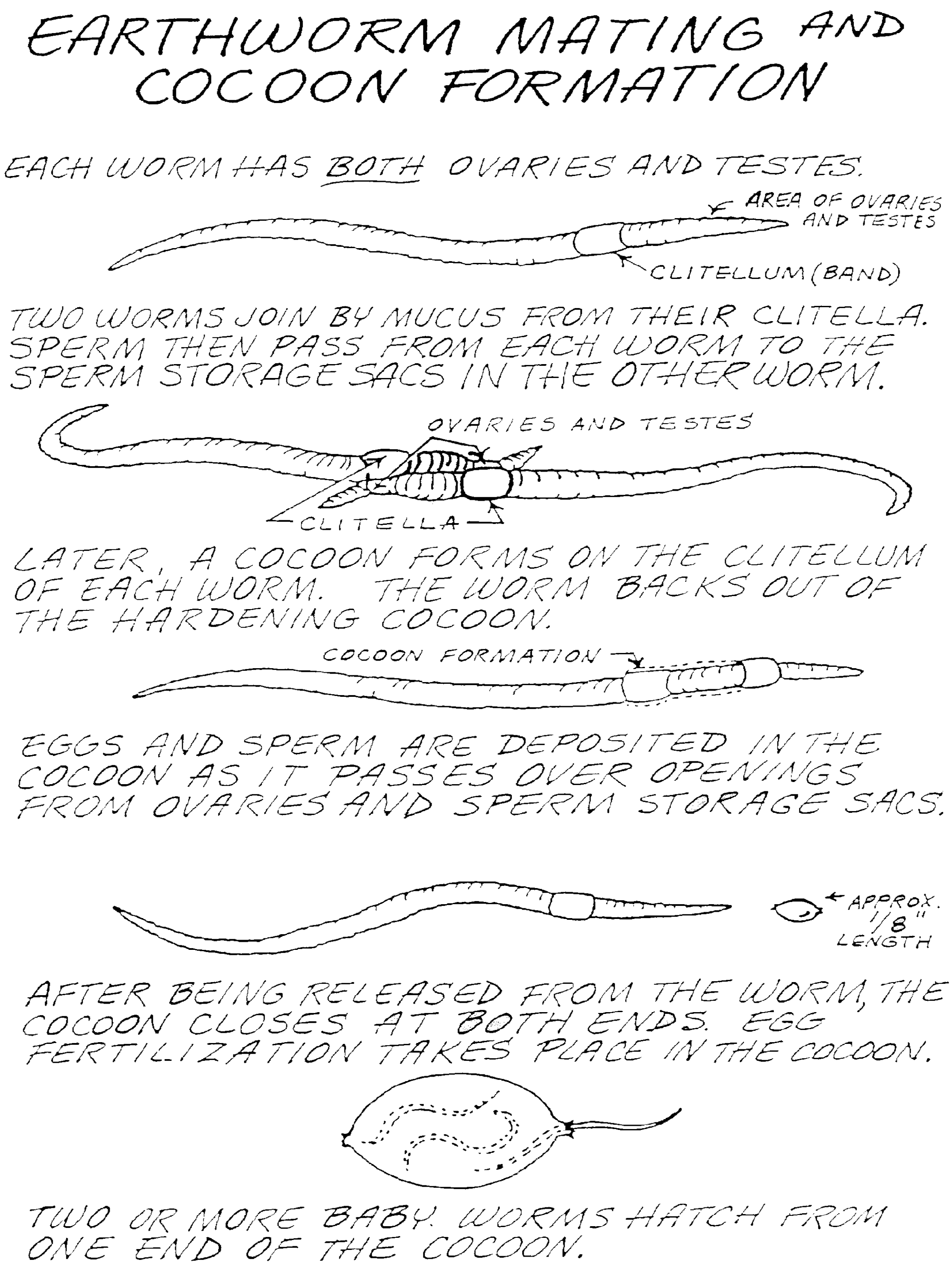
- **Digestive System**
  Like birds, worms have no teeth and rely on their crop and gizzard to grind foods. After the mouth, the digestive system of the worm is basically a straight tube made up of specialized sections that runs from pharynx to anus. Food passes from the mouth into the pharynx. The ***pharynx*** secretes mucous that moves the food into the crop. The ***crop*** is basically a thin walled storage chamber that holds food until it enters the gizzard. The ***gizzard*** is a thick, muscular organ that grinds food particles with the help of gritty materials taken in with the food. In nature, sand and other fine grit work to grind food in a worm's gizzard. Foods ground in the gizzard pass into the ***intestine***. Here intestinal bacteria digest them and the nutrients are absorbed into capillaries. Undigested materials or ***castings*** are excreted through the ***anus***. Castings are rich in nutrients and microbes (see Section 12. for a detailed discussion of worm castings).

- **Reproduction**
  Earthworms are hermaphrodites, meaning each has both male and female reproductive organs. Although worms are technically capable of self-fertilization, reproduction generally requires two different worms. Earthworms are born sexually immature and each species matures at a different age. Only mature worms have a clitellum. Earthworms find their mates by using sensory organs located on the prostomium to follow each other's slime trails.

Figure 9 illustrates earthworm mating and cocoon formation. When worms mate they lay close together with their heads pointed in opposite directions. Their bodies make contact at a point just above the clitellum so that the ovaries and testis of one worm line up with the clitellum of the other worm. During this contact sperm is exchanged and held in pores on the surface of each worm. Ova are not exchanged. Each worm holds its own ova in another pore on its surface. After sperm is passed, the worms separate. The clitellum of each worm then secretes a thick nutrient-rich mucous sheath. The outside of this sheath hardens, forming a shell, while the inside (closest to the worm's body) remains sticky. The worm then backs out of the hardening mucous, and as it backs out, the sticky inside passes over and collects the sperm and eggs from their pores and fertilization occurs. Once the mucous sacs are freed from the worms they seal on both ends and are called ***cocoons***. Cocoons are small and shaped like lemons.

Each mating often leads to multiple cocoons, and each cocoon contains several fertilized eggs. The nutrient-rich material in the cocoon feeds the

Figure 9. Earthworm Reproduction. (from *Worms Eat My Garbage*. Copyright © 1997 Flower Press. Used with permission.)



developing worms and two or more baby worms usually hatch from each cocoon. Some species mate throughout the year while others mate only during specific seasons. The number and incubation time varies with environmental conditions and with each species. Earthworms do not care for their young.

Each species of worm is a "closed species" which means that they can only reproduce and produce viable young with others of the same species. THERE IS NO SUCH THING AS A HYBRID WORM.

- **Lifespan**
  Earthworm longevity is species dependent. Various specialists report that certain species have the *potential* to live 4-8 years. In protected culture conditions (no predators, ideal conditions) individuals of *Allolobophora longa* have been kept up to 10 1/4 years, *Eisenia fetida* for 4½ years and *Lumbricus terrestris* for 6 years.

  Worms continue to grow once they reach sexual maturity but once at this stage there is a much slower increase in weight until the disappearance of the clitellum indicates the onset of old age or senescence. During this period there is a slow decline in weight until the death of the earthworm.

General characteristics of earthworms

- **Moisture, Temperature and pH Requirements**
  More than 75% of the total body weight of an earthworm is water. All earthworms are sensitive to moisture. The ideal moisture level varies with species.

  There are worm species adapted to nearly every temperature range. One species actually lives on the edges of fractured ice sheets in glaciers and feeds on blown-in pollen and algae! Thousands of species are adapted to temperate, sub-tropical and tropical climates. Only hot, dry deserts cannot support earthworms.

  Worm species vary in their pH (acid/base) tolerance. Some worms are extremely sensitive to pH and can survive only in a narrow range; others tolerate extremes.

- **Habitat**
  All earthworms can be divided into 3 categories based upon the soil they inhabit (ref. Edwards, *Soil Biol Primer*, p.H-3):

  Anecic worms: Anecic worms build and live in deep, permanent vertical burrows that extend more than 4 feet into the soil. They feed on decaying organic matter that they pull into their burrows. Anecic worms tend to be large, have low reproductive rates and long lives. They have profound effects on organic soil formation, soil porosity, water penetration and plant growth. The common nightcrawler, *Lumbricus terrestris* is an anecic worm. Nightcrawlers can live in a worm bin, but they are slow decomposers and will not reproduce in a bin. They are not recommended for vermicomposting.

  Endogeic worms: Endogeic worms move and live in the top twelve inches of the soil. They do not build permanent burrows, but instead create extensive temporary channels as they move through the soil. Endogeic worms feed on mineral soil, are medium sized, tend to be lightly pigmented or have no pigment, and have a medium life span. Because they require mineral soil to survive, they cannot survive in a worm bin and are not used in vermicomposting.

Epigeic worms: Epigeic worms are those species that prefer a plant litter environment to a soil environment. They live in or near decaying plant materials on the surface of the soil. They build no permanent burrows, feed on decaying organic material, are deeply pigmented, reproduce rapidly, tend to be small and are relatively short-lived. ***Epigeic worms are ideal for vermicomposting***. Species include *Eisenia fetida, Eisenia andrei, Perionyx excavatus* and *Eudrilus eugeneai*.

- **Predators**
  Our hard working, peaceful earthworms have enemies. Although these predators play an important role in balancing earthworm populations and ensuring genetic diversity in nature, we must strive to keep them out of our worm bins. Below is a brief description of the most common earthworm predators taken from the article entitled "Earthworm Predators" published in Worm Digest No.19.

  One of the most deadly enemies is the common mole. Moles can consume 15-20 worms each day. Because both earthworms and moles create burrows, earthworms often fall prey to moles by innocently falling into their burrows. Several larger mammals also feed on worms. These include shrews, the European hedgehog, the red fox and the European badger.
  Birds are another earthworm enemy. We have all witnessed hungry robins searching the soil for hapless worms. Other birds including black birds, starlings, thrushes, seagulls and crows also dine on worms. In addition, snakes, salamanders and toads delight in earthworms.

  Many invertebrates also prey on earthworms, including some species of centipedes, flatworms, slugs, leeches, beetles and parasitic mites.

  Despite all these natural predators, earthworms have flourished worldwide for millions of years. The biggest threat they face comes from man. Heavy mechanical tilling and indiscriminate use of pesticides and fungicides kills more earthworms than all the natural predators put together. Hopefully, armed with knowledge, we can instill a new respect for earthworms.

Why is *Eisenia fetida* the preferred species for Vermicomposting?

The goal of any vermicomposting system is to efficiently recycle organic waste into a valuable resource. An ideal system is self-contained, self-sustaining, odorless, high-yielding, low maintenance and easy to operate. The system must mimic the worm's natural environment closely enough to optimize the feeding rate and encourage reproduction. Because vermicomposting systems contain no soil, they cannot sustain burrowing or soil-eating worms and only litter feeding epigeic worms are suitable. Of the many epigeic worm species tested in vermicomposting systems, none is as well suited as the redworm, *Eisenia fetida*. It is a voracious eater and will eat a wide range of organic materials. It reproduces well in captivity and can produce over four cocoons per week, each containing three babies. *E. fetida* is a forgiving creature who tolerates human handling and a wide range of temperatures, moisture levels and pH levels. Table 9 highlights the specific characteristics of *E. fetida*.

Less Common Worms Used in Vermicomposting

Although *E. fetida* is by far the most common North American vermicomposting worm, other species are used in Europe and the tropics. Although it is doubtful that you will be called upon to answer questions about these less common worms, you may wish to familiarize yourself with them. A quick summary is provided below. More detailed information can be found in the article entitled "The Worms Themselves" in Worm Digest No. 21.

One species that commonly coexists with *E. fetida* and is probably in every worm bin in America is ***Eisenia andrei***. *E. andrei* so closely resembles *E. fetida* that even experts have difficulty identifying them. Having more than one species in a worm bin is actually beneficial. As conditions change, the species best adapted will dominate and the system will function at peak efficiency.

Most of the less common worm species cannot tolerate temperatures below 50°F and are used only in tropical climates. These include *Eudrilus eugeniae, Amynthas hawayanus, Dendrobaena veneta*, and *Polypheretima elongata.*

Table 9. Characteristics of *E. fetida.*

Size	Usually 1.25-5 inches at maturity.
Number Segments	80-120.
Color	Medium to deep red top and bottom, sometimes alternating red and buff stripes.
Setal Arrangement	Setae are closely paired.
Habitat	Epigeic (litter dweller). Builds no permanent burrows.
Temperature range tolerated	39 – 90 degrees F. Optimal range between 65 and 75 degrees F.
Moisture level preferred	Tolerates 30-100%, Optimal is 65-85%.
pH level	Tolerates pH 2-9, prefers pH 5.5-7.0.
Preferred foods	Decaying organic matter.
Appetite	At least ½ its body weight per day. Immature worms eat more than sexually mature worms (Think of them as teenagers!)
Age of sexual maturity	6 weeks.
Reproduction	Can mate year round, not seasonal. Prolific breeder, can produce over 4 cocoons per week, average 3 babies per cocoon.
Incubation time	Babies hatch after 32-73 days depending upon environmental conditions.

Because vermicomposting is in its infancy and so few worms have been studied, we can expect many exciting developments as the industry matures.

Other Creatures in the Worm Bin: The Worm Bin Food Web

Although worms are the focus of vermicomposting, they do not work alone. The decaying organic materials in a worm bin are food to a wide variety of organisms. In fact, if you consider sheer numbers, there are fewer worms in the bin than any other organism!

Figure 10 illustrates the participants in the Worm Bin Food Web. This is the same figure you saw in Chapters 2 and 3 because the backyard compost bin and the worm bin are simply two different man-made adaptations of natural decomposition. Both are systems to reduce solid waste. A vermicomposting system is simply controlled in such a way to encourage many more redworms than would be found in a backyard system.

Bacteria, Fungi, Actinomycetes: As in the backyard bin, the primary decomposers--bacteria, fungi and actinomycetes, are the most numerous organisms in the bin. They enzymatically break down and soften the raw organic matter to a state that the worms can digest.

Microscopic protozoa, nematodes: These diverse microscopic organisms are secondary decomposers that feed on bacteria.

Springtails (Colembola): Open any healthy worm bin and you'll see tiny white specks hopping around amid the decomposing material. Those specks are hardworking springtails. These tiny wingless insects are important primary decomposers of organic matter and the excrement of other animals.

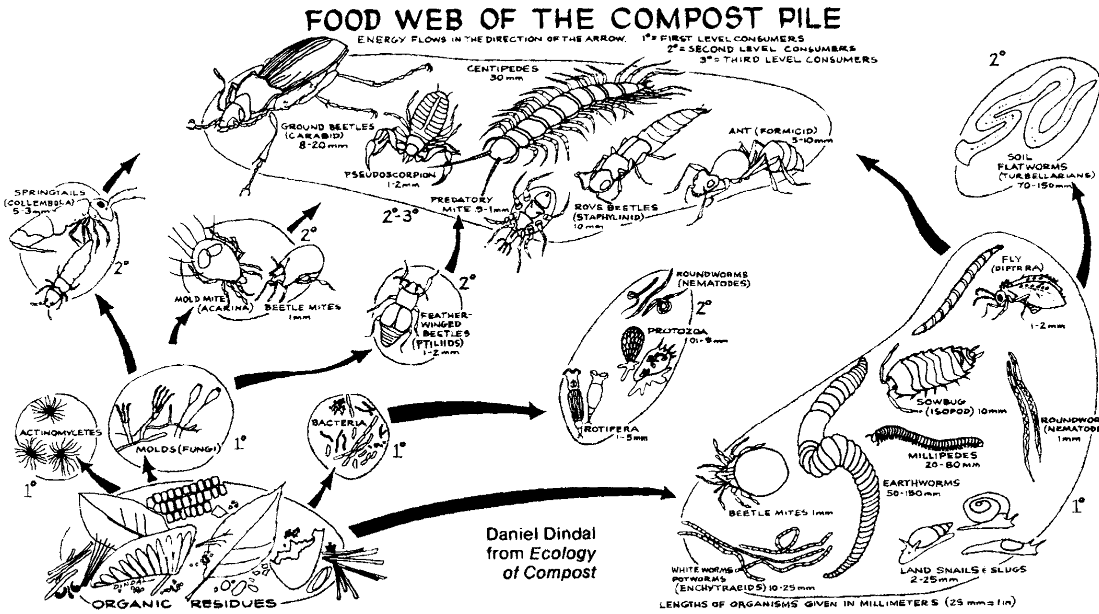
Sow or pill bugs (Isopoda): The same "rolly polly" crustaceans you see in the backyard compost bin inhabit worm bins. Technically, the two belong to different species and the pill bugs roll up when threatened and sow bugs do not. They shred and consume tough woody, high celluose materials, making them easier for the worms to digest.

Mites (Acarina): Many different mite species inhabit a worm bin. Mites are tiny, spider-like insects that range in color from brown to red, to glossy white. By and large they are beneficial to a worm bin, but sometimes their populations can become so large that they stress the worms.

Pot Worms (Enchytraeids): Pot worms are tiny, threadlike, segmented white worms that are barely visible to the naked eye. Many people mistake them for baby redworms. They are beneficial and usually appear in a worm bins with a lot of finished vermicompost. As an added bonus, pot worms are prized as tropical fish food and some worm growers culture this species of worm as pet food.

Millipedes (Diploda) and Centipedes (Chilopoda): Millipedes and centipedes are often confused. Both are long, tubular creatures with many legs, but the similarity ends there. Millipedes are SLOW moving, beneficial decomposers of organic matter. Centipedes on the other hand are FAST moving predators that prey on beneficial insects and worms. Centipedes DO NOT benefit a worm bin and should be killed on sight.

Figure 10. Compost Food Web. From Dindal 1971, *Ecology of Compost*.



Fruit Flies (Diptera): Although many home vermicomposters can tell long tales of fruit fly woe, these tiny flies and their larvae are actually voracious decomposers. Although they are distasteful to humans, they pose no health threat and are beneficial to the worm bin. Methods to control fruit flies will be discussed in Section C: Troubleshooting a Worm Bin.

Fungus gnats (Diptera): These tiny black flies feed on fungi and are similar in appearance to fruit flies. Methods to control fungus gnats will be discussed in Section C: Troubleshooting a Worm Bin.

What is that rich, brown, crumbly material in my worm bin?

The end product harvested from a worm bin is called vermicompost. ***Vermicompost is a "dark mixture of worm castings, organic material, and bedding in various stages of decomposition, plus living earthworms, cocoons and other organisms present"*** (ref. Appelhof, *Worms Eat My Garbage*, p.110). Every harvest produces vermicompost with varying amounts of worm castings.

Worm castings are "deposits that moved through the digestive tract of the worm"(ref. Appelhof, *Worms Eat My Garbage*, p.110), or to put it bluntly, worm manure. Worms are in many ways a small version of a cow, in that the bacteria and fungi in a worm's gut digest the food for the worm. The digestive tract of the worm is an amazing "bioreactor". The worms "ingest sand, silt, clay, dead plant material, bacteria, fungi, protozoa, nematodes, the odd insect larva, microarthropods and so forth. Inside the gut of the worm, conditions are perfect (good moisture and we believe, well-aerated) for the bacteria and fungi to speed up their growth processes and decompose more organic matter." (ref. Soil Food Web [Online], Available at www.soilfoodweb.com/). As organic matter passes through the worm's gut, it undergoes "chemical changes, deodorization and neutralization, so that the resultant ***castings are a practically neutral humus, rich in water-soluble plant food, immediately available for plant nutrition***" (ref. Barrett, *Harnessing the Earthworm* p.9). Worm castings contain as much as 40% more humus than is normally found in the top six inches of soil. In addition, worm castings are alive with thousands of beneficial bacteria and fungi. These organisms literally cover the root and leaf surfaces of plants, making them resistant to pathogenic attack.

How does Vermicompost differ from Yard Waste Compost?

In Chapter 2, we learned that humus is a complex system of large molecules whose composition varies depending on the unique combination of simple building blocks that make up each sample. Humus provides color, structure, porosity, drainage and moisture holding capacity to the soil. Although both finished compost and vermicompost are considered humus and there is a great deal of overlap between the two, they differ in several important ways.

Chemical Composition of Vermicompost

- **pH:** Like yard waste compost, vermicompost is considered almost pH neutral. Both vermicompost and backyard compost act as buffers in the soil, helping maintain a steady acid-base balance.

- **N-P-K:** Although ***N-P-K*** levels [percentage of Nitrogen (N), Phosphorus (P) and Potassium (K)] vary with feedstock**,** vermicompost in general is richer in nutrients than yard waste compost. As the worms digest and excrete organic matter, they concentrate nitrogen and other nutrients in their castings. Because castings pack more nutrients into a smaller volume, the nutrient percentages rise. N-P-K levels as high as 4-3-4 have been reported (Holcombe, *Casting Call*, 3(2), p.2), but an N-P-K of 1-1-1 is probably more typical. As far as plants are concerned, the amount of nitrogen is not as important as the chemical form of that nitrogen. The nitrogen in vermicompost is nitrate nitrogen, a form more available to plant roots than the ammonium nitrogen found in backyard compost (ref. Subler, *BioCycle*, 39(7), p.64).

- **Micronutrients**: Like yard waste compost, vermicompost also contains bioavailable magnesium, calcium, sodium, iron, manganese, copper, zinc and boron. All these trace nutrients are necessary for plant growth.

- **Heavy metals:** Humus of any kind has the capacity to bind toxic heavy metals and prevent plants from absorbing them. Because vermicompost is rich in humus, it plays an important role in soil detoxification.

Biological Composition of Vermicompost

The real value of vermicompost lies in its teeming microbial life. Studies done by Dr. Clive Edwards and his associates at the Ohio State University show that "vermicomposts were clearly distinguishable from [yard waste] composts, in that they had significantly greater cumulative microbial activity than the composts" and that "there are distinct differences between microbial communities found in vermicomposts and composts" (ref. Subler, *BioCycle* 39(7), p.63-66). They attribute their findings to the metabolic differences between the thermophilic bacteria that dominate the backyard system and the bacteria that line the guts of the worms. The microbes found in vermicompost are thought to play important roles in plant growth and disease resistance.

In addition to beneficial microbes, vermicompost is thought to "contain hormone-like compounds that accelerate plant growth." (ref. Dominquez, *BioCycle* 38(4), p.57-59).

Pathogen/Weed Seed Content of Vermicompost

In a yard waste compost pile, sustained high temperatures effectively kill most plant pathogens and weeds. As you know, vermicompost does NOT go through a thermophilic phase, and you may fear that vermicompost may contain pathogens and weeds. Although little data is available, preliminary studies show that many weed seeds and pathogens (including human disease pathogens) are destroyed as they pass through the worm's digestive tract. Worms "ingest the root-feeding nematodes, the pathogenic bacteria and fungi and the small size weed seeds. What they don't consume gets released from their bodies as fecal material, but in that material, pathogens, root-feeding nematodes and weed seeds have a very difficult time surviving the burst of growth of other organisms" (ref. Ingham, *BioCycle*, 39(11), p.18).

In summary, vermicompost is a storehouse of plant nutrients, growth stimulators and beneficial microbes. It is vital to soil porosity, it aids in moisture retention and it contributes to soil structure. A "gardener's gold", vermicompost truly brings life to sand, silt and clay.

Using Vermicompost

- **Seed Beds:** Spreading a little vermicompost into a prepared seed row will provide germinating seeds and seedlings with nutrients and beneficial microbes.

- **Top Dressing:** Vermicompost can be used to top-dress plants. To top-dress, simply sprinkle vermicompost about ¼" deep around the base of each plant out to the drip line (ref. Appelhof, *Worms Eat My Garbage,* p.118). Vermicompost is rich in available plant nutrients and a little goes a long way. Unfortunately, you will rarely have enough vermicompost to top dress all your plants. Make sure to gently work the vermicompost into the soil with a garden fork so that it does not dry out on the soil surface. ***Completely dry worm compost is impossible to rewet, low in microbial life and will not release its nutrients into the soil.***

- **Transplanting:** When transplanting vegetable, flower or ornamental plant seedlings, simply toss a handful of vermicompost into the prepared hole; add the seedling and soil and water in.

- **Potting Media:** Vermicompost can be used to supply up to ¼ the volume of potting media.

- **Vermicompost Tea:** Like backyard compost, vermicompost can be extracted to make a microbially rich tea (for details, see Chapter 3). Because the mix of organisms in vermicompost differs from that present in backyard compost, the resulting tea will differ. One of the exciting frontiers of compost usage is to tailor teas to individual plants. It is hoped that plant-specific teas can reduce or eliminate the need for chemical fertilizers and pesticides. Much research into the complex relationship between beneficial bacteria, fungi, protozoa, nematodes and plant growth is needed to fully understand and develop effective compost teas.

C. Tricks of the Trade: Tricky Worm Questions

Q: Is there any danger in handling the worms or vermicompost?

A: For most healthy people, a worm bin poses no danger**.** A worm bin will tend to grow a lot of fungus and sensitive and immunosuppressed individuals may need to exercise caution.

Q: Do the worms keep reproducing forever in the bin? What happens when there are too many?

A: A worm bin is a self-regulating ecosystem. Available food, oxygen and predators regulate worm reproduction rates in nature and in the worm bin.

Chapter 6

Worm Bins and Systems

Terms Defined in this Chapter:

Bedding
Continuous Flow System
Dump and Sort
Forced Screening
Harvest
Harvesting
Hi-tech vermicomposting system
Lateral Movement System
Layer feeding
Leachate
Migration Method
Pocket feeding
Quick and Dirty
Self-Screening
Simple bin
Stacking Tray System
Top feeding
Worm bin
Worm crawl
Worm fork

A. Objectives

1. Become familiar with both low and hi-tech worm bin systems.
2. Be able to set up a simple worm bin.
3. Understand the pros and cons of various harvesting methods.
4. Know how to troubleshoot common problems.

B. Study Materials

Recommending a Vermicomposting System

Composting worms are oxygen-breathing animals that require a moist, dark, temperate, vibration-free environment and a ready source of decaying organic matter. Their human companions prefer a small, attractive, convenient, odor-free, inexpensive, low maintenance system. The best vermicomposting systems are designed to mimic the redworm's ideal natural environment in a way that appeals to humans. Although open systems and windrows can be managed to encourage worms, home vermicomposting systems are easier to maintain if they are housed in a bin. ***"A worm bin is any container that corrals the worms and the composting activity"*** (see Worm Digest No. 23). As you will learn, systems can be as simple as a plastic box or as complex as an entrepreneurial builder can conceive.

As a Master Composter/Recyclers, we must become familiar enough with the common worm bin systems to recommend the system best suited to the individual's needs. Many people see their first worm bin at one of our workshops or fair booths and are intrigued by the concept, but need more information to get started. To help ensure that they have a positive first experience, we must assess their needs and level of knowledge. The most important questions to ask a prospective vermicomposter are:

1. How much food waste do you generate each week?
2. Do you want a system that will handle all your food waste?
3. Where would you like to place your system? Are aesthetics a concern?
4. Would you prefer one large bin or several smaller ones?
5. Are you a do-it-yourselfer or would you prefer to buy a ready-made system?
6. Is cost a factor?
7. Would you like hands-on contact with the worms or prefer to keep your distance?
8. How much work are you willing to do to maintain and harvest the bin?
9. What would you like to do with the finished vermicompost?

Many novices will not have ready answers to these questions and may need more information. Feel free to direct them to our Wormshops and to Mary Appelhof's *Worms Eat My Garbage.*

How Big a Bin?

The right size bin is vital to successful vermicomposting. Bin size is important to both the worms and their humans. Because *Eisenia fetida* are epigeic worms (surface feeding), the bin should be fairly shallow, ***no more than 18"-24" deep***. In addition, a successful worm bin must support enough worms to handle a family's food waste. The number of pounds of food waste/week determines the correct bin size. The easiest way to determine how much food waste is generated is to weigh it. Simply weigh your scraps every day or save them for a week and weigh the accumulated waste. For even more accuracy, weigh food wastes for several weeks and determine a weekly average. ***One square foot of bin surface area is required for each pound of food waste/week.*** A typical, non-vegetarian family of four produces about 6 pounds of food scraps per week and would need 6 square feet of bin surface area. As you will see in Section 8, adequate surface area can be obtained in several creative ways.

Where to Put a Worm Bin

Once a prospective vermicomposter knows how big a bin she'll need, the next step is to decide where to place it. It is important to consider many factors when locating a bin. These include:

- **Convenience/Appearance:** Because compostable food wastes are generated almost daily, it is important to locate a worm bin near the waste source. One of the real advantages to vermicomposting is its flexibility. Worm bins can be successfully managed indoors, in garages, in basements and outdoors. Most systems are attractive, and some connoisseurs even build furniture-quality bins designed for living room use!

- **Temperature Control:** Although *E. fetida* can tolerate a fairly wide temperature range, they are happiest between 65° and 75°F. In other words, worms thrive in the same temperature range as we do. In cold climates, worm bins can be kept indoors or in a basement or garage. Although large outdoor bins tend to be self-insulating, during extremely cold weather, covering them with blankets, Styrofoam panels or hay bales can insulate them. In hot weather, it is important to keep a worm bin wet (approximately 70% moisture). A wet bin will maintain its temperature through evaporation.

- **Vibration Control:** All worms are sensitive to vibration and will attempt to flee from its source. If they cannot flee, they will panic and eventually die of neural shock. No worm bin should be placed near an air conditioning compressor, clothes dryer, or any other source of vibration.

- **Aeration:** Worms are oxygen-breathing animals. Any worm bin must provide a system of airflow and be placed in an area free of toxic fumes.

- **Predator Control:** Any outdoor system must be protected from dogs, cats, birds, rodents and amphibian predators. A heavy bottom and top cover are usually adequate.

Which Bin is Best?

After deciding upon size and location, it's time to select a bin system. Before the early 1990's, virtually all bins were homemade wooden or plastic bins. Since then, consumer demand has fueled the creative fires of several entrepreneurs and their efforts have produced impressive hi-tech products.

Simple Bin Systems

Simple bins are by far the most commonly used. They appeal to the novice and expert alike. All low-tech vermicomposting systems share the same basic characteristics and are bedded, fed and harvested in the same ways. ***Virtually any opaque, non-toxic material can be used to build a worm bin.*** *Eisenia fetida* is exquisitely sensitive to light and will die if exposed for more than about 20 minutes. It is vital that an opaque material is used for the bin and that the system is covered. Wood and plastic are the most common materials used and simple systems can be homemade or purchased commercially.

Simple Plastic Bins

Probably the most common and widely used worm bins are plastic. Plastic bins are ***cheap and readily available***. Because they are usually ***small and neat***, they will fit anywhere and can be easily moved. In addition, plastic is inherently ***resistant to moisture and will not decompose***. A popular homemade bin can be made by retrofitting a 14-33 gallon plastic storage container with the ***Worm World-Insert Kit***. This kit is available through Beaver River Associates and consists of two air vents, a plastic tube and spigot, Styrofoam base material and a series of screens.

Of course, any plastic bin can be used to make a serviceable worm bin. Obviously, one should avoid re-using any plastic container that previously held pesticides or other toxic chemicals. Simple plastic worm bins are also available commercially. They include the Worm-a-Way, A Worm Friendly Habitat, the Worm Factory, and Worm's World Home Vermicomposting Units. For in-depth reviews of each of these commercial systems, see Worm Digest No. 23.

Despite their many advantages, most simple plastic bins are too small to handle an entire family's wastes. Many people solve this problem by owning several small bins. Finally, unlike wood, ***plastic bins require careful attention to aeration and have a tendency to become too wet***.

Simple Wooden Bins

A popular alternative to a plastic worm bin is a simple homemade wooden bin. Wood has many advantages. First, ***wooden bins "breathe".*** Because it is naturally porous, wood facilitates the movement of oxygen and moisture. Secondly, wooden bins are ***easy to build.*** Only minimal woodworking skills and tools are required. Mary Appelhof's book, *Worms Eat My Garbage*, Chapter 3, also gives detailed construction directions. Wooden bins are usually built from cheap plywood or recycled wood. (Please note: do not use any sort of chemically treated wood to build a worm bin. The chemical additives used to extend the outdoor life of wood are very toxic to worms.) Finally, ***one of the real advantages of wooden systems is their flexibility***. The dimensions of the bin can be altered to suit the homeowner as long as the depth never exceeds 18"-24".

Like plastic bins, wooden bins have some drawbacks. The most serious is their ***relatively short life.*** Wood is an organic material and it will eventually decompose along with its contents. The average outdoor wooden bin lasts approximately 3-5 years. In addition, wooden bins are ***heavy and difficult to move.***

High-tech Vermicomposting Systems

Hi-tech systems are generally designed to reduce or eliminate the labor and time-intensive work of separating the worms from the finished vermicompost. Hi-tech systems can be divided into three basic types: **Stacking Tray Systems** like the Can-O-Worms and the Wriggly Ranch, **Continuous Flow Systems** like the Earth Factory and the Eliminator, and **Lateral Movement Systems** like, the Worm-A-Roo. Each has advantages and disadvantages. Please refer to Worm Digest, No. 23 for in-depth reviews of each system.

Handy Tools and Gadgets

Besides a bin, no tools are really required for vermicomposting. However, a few handy additions will make vermicomposting more convenient. These include:

- **Two food waste collecting containers with lids** (great use for those large yogurt and cottage cheese containers). Unless you dump your food wastes every day, these covered containers contain the mess and reduce the likelihood of a fruit fly invasion.

- **A three pronged *worm-fork* or dull garden fork**. Forks are very handy for feeding, monitoring and harvesting a bin. Worm forks have flattened blades that are less likely to impale the worms. They are available through worm bin manufacturers. A dull 3-prong garden fork also works well, and a small garden shovel will do in a pinch.

- **A compost screen** may be used to break up clumps of finished vermicompost and generate a uniformly sized end product.

Creating a Worm Friendly Habitat in Your Bin

No matter which bin is selected, it is important to create a healthy worm habitat. Preparing and placing appropriate ***bedding*** into the worm bin is the first step. Bedding refers to the ***non-food waste, fibrous material placed in a worm bin***. Bedding is required for several reasons. First, bedding aids in aeration. Food wastes tend to be wet and soft, leading to compaction and anaerobic conditions. Fibrous bedding materials such as shredded dried leaves, shredded cardboard or paper, coir fiber and straw help maintain pore space for oxygen penetration. Usually, two or more of these materials are combined to vary particle size and ensure they don't compact. Second, food wastes tend to have high nitrogen content, and must be balanced with a carbon source in order to encourage rapid microbial decomposition. Remember, worms have no teeth and can only consume the softened, partially rotted remains of microbial decomposition.

The type, amount and technique for adding bedding to a worm bin varies with the bin type.

- **Bedding a Simple Wooden or Plastic Bin:** The ideal moisture level for *E. fetida* is 65%-85%. Any bedding material must be moistened with water until a handful of it feels a little wetter than a wrung out sponge i.e., a few drops of water fall when the material is squeezed. Most bedding materials can be soaked in water briefly before they are added to a bin, but straw must be soaked overnight to ensure adequate hydration. Simple bins are bedded by mixing enough damp bedding material to fill approximately 2/3 the bin capacity.

- **Bedding a Hi-Tech Worm Bin:** All hi-tech systems come with detailed bedding instructions. Please see Worm Digest No. 23 for details.

Worms: Where to find them and how many?

After the bedding has been selected and the moisture level is correct, it is time to add the worms. How many worms are needed to start a bin? Theoretically, two worms would eventually populate an entire bin, but the ***average home system requires at least 500-1000 worms to quickly jump-start the system***. If well fed, the starter worms will reproduce rapidly and quickly populate the entire bin.

Several free and low cost worm sources are available. In addition, many commercially available vermicomposting systems include the worms in the purchase price. Worms can be obtained from a friend with a worm bin, from the manure pile of a nearby farm or from commercial worm growers. Remember, KNOW YOUR WORMS! ***It is vital to use Eisenia fetida (or a combination of E. fetida and E. andrei) in a vermicomposting system***. Worms are usually sold by weight. **One pound of *E. fetid*a is equivalent to approximately 1000 worms.** Worms are usually shipped in moist peat moss or vermicompost and should be added to a prepared worm bin immediately upon receipt. Adding the worms is as simple as upending the container over the bedding and dumping out the worms! They will quickly make themselves at home.

Local worm sources are listed on the flier entitled "Redworm Sources" that is included in this section.

Food: What to Feed Your Worms and What NOT to Feed Your Worms

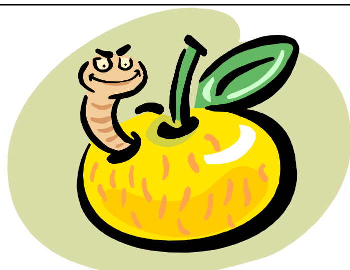
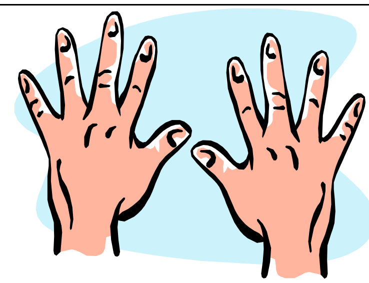
Composting worms are amazing creatures that, *in nature*, eat ANYTHING that was once living. Natural foods include decaying plant materials, dead animals, and animal feces. As former Worm Digest editor, Kelly Slocum says, "Our forests would be knee-deep in animal carcasses without worms and their voracious appetites!" Unfortunately, foods acceptable in the forest are not acceptable in a home worm bin. Remember that a worm bin is a controlled system living in a human world without the checks and balances of nature. A few simple rules will keep the worms happy and your bin safe and odor-free. Table 10 is a guideline for feeding your worm bin. The feeding categories are general and include many specific foods.

and vermin, tend to degrade anaerobically and stink. Pet and human feces may contain pathogens and never belong in a worm bin.

Food: How to Feed Your Worms

There are two main methods to feed a worm

Table 10. What to Feed and What Not to Feed Your Worm Bin.

 **DO FEED** YOUR WORM BIN	 **DO NOT FEED** YOUR WORM BIN
Vegetable peelings, scraps (free of cooking oils)	Meat
Fruit peels, scraps*	Fat
Cereal (no milk)	Bones
Coffee grounds, tea (filters, bags and all!)	Fish
Egg shells	Whole eggs
Maple syrup, molasses (yes, you can add the pancakes your kids won't eat)	Oils including margarine, cooking oil, lard, grease
Bread, muffins, pizza crusts (free of cheese, butter or margarine)	Dairy products including milk, butter, cheese, whole eggs
Paper napkins, paper plates, tissues	Pet or human feces
All those moldy "science experiments" in the back of the refrigerator	Non-biodegradable materials like the rubber bands encircling green onions and asparagus

*Please note: large quantities of citrus rinds may be toxic to worms; add in moderation.

Several books, including *Worms Eat My Garbage* discuss adding small amounts of meat and cheese. Although an experienced vermicomposter may successfully compost meat, we do not recommend this practice. Meat, fats, oils and dairy products attract flies

bin: ***pocket feeding*** and ***top or layer feeding.*** Pocket feeding is the most commonly used method for low-tech simple bins. Many of the hi-tech bins employ top or layer feeding techniques.

- **Pocket feeding:** For pocket feeding, the bin is bedded to a depth of 12"-18". At each feeding, a small hole or pocket is dug into the bedding and the food deposited within. The pocket is then covered with a bit of bedding. Each time the system is fed, a pocket is dug into a new area. No new bedding is added, only feed stock. In this way, food, in varying states of decay, is eventually spread throughout the system. The worms then work in all layers of material. ***The greatest advantage of pocket feeding is its simplicity. It requires no addition of material besides food and is in essence a "throw and go" system***. The only drawback to pocket feeding is that, because worms are working in all layers of the system, it is more laborious to separate them from the finished compost at harvest time.

- **Top or layer feeding:** Although it can be used in any system, top feeding is primarily used in hi-tech systems. Using the top feeding method involves bedding the bin to a depth of 2"-8" (some systems require specialized bedding for first layer), layering 1-2" of food waste on top and covering with 1-2" more bedding. Each time the system is fed, the procedure is repeated. When done correctly, the worms consume all the food in each level as they work their way up to the freshest food. ***In top or layer feeding, the worms stay near the surface making them easy to separate from the finished vermicompost at harvest time.*** On the down side, one must have a handy stock of bedding material to add at each feeding and some hi-tech systems require specialized bedding.

Harvesting a Simple Worm Bin

You've carefully selected and bedded your bins, the worms are happy and healthy and you're diverting all your vegetable and fruit scraps from the waste stream. After a couple months, you notice an accumulation of a rich, moist, dark brown, soil-like material. Only the newest food scraps are recognizable and the bedding is disappearing quickly. After about 4-6 months, the bin takes on a delicious earthy aroma and the brown material is beginning to fill the bin. The time has come to reap your reward. Yes, it's time to harvest the bin.

The term ***harvesting refers to the separation and removal of the worms from the finished vermicompost***. The methods outlined below apply ONLY to simple, low-tech vermicomposting systems. The pros and cons of each method are outlined in Table 11. Hi-tech commercial systems are designed to be "self-harvesting" and come with detailed instructions. Please see Worm Digest No. 23 for a description of each system.

- **Quick and Dirty Method:** Remove 2/3 of the contents of the worm bin and use it, worms and all, in the garden. Rebed the bin and allow the remaining worms to repopulate the bin.

- **Dump and Sort Method**: Dump the entire contents of the worm bin onto a tarp under bright light or in the sun. Mound the material into several small cone shaped piles. Because the worms are photophobic, they will dive down in the piles to avoid the light. Scrape the material from the top of the piles until you expose the worms and wait for them to move down through the material again. Keep scraping off the tops of the vermicompost piles until there is nothing but worms left. Re-bed the bin, replace the worms and operate as normal.

- **Migration Method:** Scrape as much finished material as possible to one side of the bin. Fill the empty side with new bedding and operate the bin as you normally would, feeding ONLY the freshly bedded side. In approximately 4 weeks the worms will leave the finished material and migrate to the freshly bedded side. At that time, remove the finished compost and fill the space with new bedding and continue operating as normal.

- **Forced Screening Method:** Spread the entire contents of the finished worm bin onto a ¼” to ½” mesh screen. Hold the screen over a wheelbarrow and shine a bright light directly over the material. The worms, in an effort to avoid the light will dive down into the material and fall through the screen. When there are no more worms falling from the bottom of the screen, remove the screen and retrieve the worms from the wheelbarrow. Place the worms into a freshly bedded bin.

- **Self-Screening Method:** Cut a piece of window screening larger than the surface area of the worm bin. Lay this screen on top of the finished material with the excess length laying flat against the sides of the bin. Re-bed the bin on top of the screening and feed as normal. The young worms will easily crawl up through the screen seeking the food in the upper part of the system. Mature worms will have to work at squeezing through the small holes and will remain in the lower layer of material. They will continue feeding until they have converted all the food into finished castings. Once they have consumed all available food beneath the screen, they will go through the effort to squeeze through the screen (remember worms are 75% water and are very flexible) into the upper layer. This process takes about 4 MONTHS. After that time, the screen and the upper layer of worms and organic matter can be lifted out and set aside. The finished compost on the bottom can then be removed and the top materials and fresh bedding put back into the bin. Operate the bin as normal from this point until the next harvest. At that time, simply lay the screen on top of the nearly finished material and feed above.

Storing Vermicompost

Once vermicompost is harvested, it can be stored in an ***aerated container*** for several months. Aeration is important, because the harvested material will continue to slowly decompose after it is removed from the worm bin. A few worms may remain in the harvested material and babies may hatch from harvested cocoons. Lack of oxygen will kill the worms and the material will become anaerobic, foul smelling and toxic.

It is important to make sure that vermicompost stays moist (no drier than commercial potting soil) because once it dries out completely it is impossible to rewet. In addition, moisture nourishes the beneficial microbes that are an important component of vermicompost.

C. Tricks of the Trade: Troubleshooting a Worm Bin

Most worm bins are low maintenance and virtually trouble-free. Occasionally a bin runs into trouble. One of the prime symptoms of an

Table 11. Pros and Cons of Worm Bin Harvesting Methods.

Worm Bin Harvesting Method	Pros	Cons
Quick and Dirty	Fast, easy, no sorting.	Many worms, cocoons and unfinished organic matter lost. Must reduce feeding load until system repopulates.
Dump and Sort	Very few worms lost.	Slow, labor-intensive, tedious. Difficult to dump large, heavy bins. Cocoons generally lost in finished compost.
Migration	Relatively easy. Few worms and cocoons lost.	Slow. Must take care to feed on one side only. Reduces usable worm bin area by half.
Forced Screening	Fast.	Rough separation. Cocoons generally lost in finished compost.
Self-Screening	Very little human labor involved. Virtually no worms or cocoons lost.	Slow. Reduces usable worm bin area by half.

unhealthy bin is ***worm crawl***. Worm crawl refers to the action taken by worms desperately trying to escape adverse conditions. The most common causes of worm crawl are excess moisture, excess vibration, low oxygen levels and anaerobic conditions. Other problems are more a nuisance to humans than a danger to the worms. A few tips will solve the most common problems.

Q: My worm bin seems too wet (or dry), what can I do?

A: A handful of material from a healthy bin will feel a little wetter than a wrung out sponge. A few drops of water should fall. If it is too wet, oxygen levels may drop to the point that anaerobic organisms and their associated toxins and odors predominate. Although worms can survive under water providing it is *well oxygenated*, extremely wet bins can become so compacted and oxygen starved that the worms die. At the other extreme, a bin can become too dry to sustain the worms. It is important to check the system regularly to ensure adequate moisture. If a bin gets too wet, one can either drain the excess liquid or add fresh dry bedding to absorb the excess. If a bin dries out, simply add water or wet feed items like melon.

Q: Why does my worm bin develop unpleasant odors sometimes?

A: Although worms are phenomenal eaters, people sometimes generate more food waste than their bin can handle. An **overfed bin** may become anaerobic and develop nasty odors. The simplest way to handle the problem is temporarily stop feeding the bin, turn the existing materials in the bin to aerate them and then add fresh bedding. In the meantime, you can add your food scraps to your backyard compost bin or remove some of the worms and bedding from the main bin and start a temporary bin with the new scraps until the original bin recovers.

Q: Help! I'm being attacked by an army of fruit flies.

A: Although they drive humans insane, your worms are not bothered by fruit flies. If a bin is kept outdoors, fruit flies are merely a nuisance, but they present a real problem for indoor bins. Fruit fly larvae are often present on bananas and other tropical fruits. These larvae hatch in the rich environment of your worm bin and once a few hatchlings mature, they multiply rapidly. One of the best solutions is prevention. First, it is important to bury all food wastes and cover the top of the bedding with a few sheets of damp newspaper or cardboard (a great use for old pizza boxes). Another great suggestion is to freeze all scraps before adding them (thawed, of course) to the bin. The frigid temperature kills the fruit fly larvae. For the hunters among us, Mary Appelhof suggests several ingenious fruit fly traps in Chapter 9 of *Worms Eat My Garbage.*

Q: There are tiny flies in my worm bin that don't seem like fruit flies, what are they?

A: Probably Fungus gnats**.** Fungus gnats may be more than a nuisance. These tiny flies resemble fruit flies and they feed on the fungi growing in worm bins. Unfortunately, they also feed on plant roots and can be a problem in homes with indoor bins and prized houseplants. The best defense is prevention. Keep the bedding covered with several sheets of damp newspaper or cardboard and limit the amount of food added to the bin.

Q: I'm mixing browns and greens in my worm bin, why doesn't it get hot?

A: Good question! Although your worm bin operates in much the same way as a backyard compost bin, the system is designed to favor earthworms. ***The main reasons worm bins do not usually become thermophilic are their relatively small size and their high moisture content.*** Home size worm bins are too small to hold much heat. Whatever heat is generated is usually rapidly dissipated through the bin walls or cooled by the evaporative properties of the bin's moisture. A home worm bin can become too hot if it is overfed. Vast excesses of organic matter will support rapid bacterial growth and can become thermophilic. Commercial vermicomposters are plagued by temperature regulation problems. Their huge bins must be carefully fed and monitored to ensure they do not become hot enough to kill the worms.

Chapter 7

Grasscycling

A. Objectives

1. Define grasscycling.
2. Describe the benefits of grasscycling.
3. Be able to explain the grasscycling method of lawn care to the public.
4. Understand why grasscycling does not cause thatch.
5. Describe the advantages and disadvantages of various lawn mowers.

Terms Defined in this Chapter:

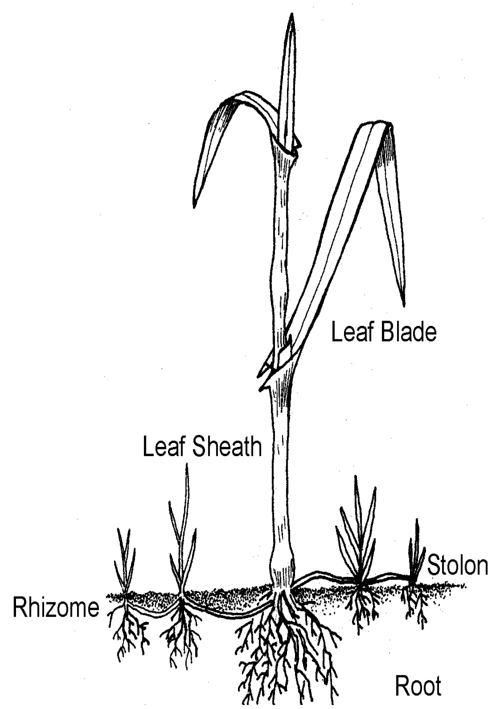
Blade
Bud
Cool season grass
Grasscycling
N-P-K
Node
Rhizome
Sheath
Stolon
Thatch

B. Study Materials

Turf Biology 101

Lawns in Eastern Washington are usually seeded with a mixture of several ***cool-season*** (adapted to cooler climates) grass species. Most common are perennial ryegrasses, fescues, and Kentucky bluegrass. Although each species has its advantages and disadvantages, all grasses share the same fundamental biology. Fig. 11 illustrates the basic parts of a grass plant. Anything above ground is called a "shoot". The shoot is composed of a central stem and leaves. Note that grass leaves are composed of two parts, a ***sheath*** and a ***blade***. The sheath wraps around the stem and the leafy blade grows away from the stem. Have you ever wondered why grass continues to grow after we cut off part of its stem by mowing? If you run your fingers up the stem, you will feel several swollen areas called "nodes". Leaves bud from these nodes. When we mow the top of the grass stem, the remaining buds form a new leafy top (ref.

Figure 11. Anatomy of a Grass Plant.
(from *The Chemical-Free Lawn*. Copyright ©1989 Rodale Press. Used with permission.)



Green, *The Everything Lawn Care Book,* p.2). Most desirable turf grasses spread by ***rhizomes*** and ***stolons***, propagative stems that grow below and above ground, respectively. Like all plants, the grass root anchors the plant, absorbs and stores nutrients and water, and produces important plant hormones. Compared to other plants the grass root is relatively shallow and very fibrous. It is extremely efficient in collecting water and food allowing grasses to withstand long periods of drought (ref. Green, *The Everything Lawn Care Book,* p.4).

What is Grasscycling?

Grasscycling is basically ***leaving cut grass on the lawn***. Grasscycling mimics composting and natural humus formation in that grass clippings provide the decaying organic litter that feeds the Soil Food Web. As you know, fresh grass clippings, especially spring clippings, are a valuable green (nitrogen source). The nitrogen levels of spring grass are equivalent to that of the best cow or horse manure (ref. Solomon, *Organic Gardener's Composting*, p.47).

Why Grasscycle?

The Grasscycling method of lawn care is arguably the best. Not only does it protect the environment, it also produces an enviably beautiful lawn. ***Remember that a lawn is only as healthy as the soil supporting it***. A good turf must be well fed. All lawns need nitrogen, phosphorus and potassium. Although it is always wise to test individual soils, studies conducted by Washington State University demonstrate that generally ***fertilizers with an N-P-K of 3-1-2 are best for Western Washington lawns*** (ref. Stahnke, *Turfgrass pub.EB1280*). Chemical fertilizers are labeled to indicate how much nitrogen, phosphorus and potassium they contain. A fertilizer labeled 15-5-10 contains 15% nitrogen (N), 5% phosphorus (P) and 10% potassium (K). Therefore a 10lb bag of this fertilizer would contain 1.5-lbs. available nitrogen, 0.5-lbs. available phosphorus and 1.0-lbs. available potassium. ***Washington lawns need 4lbs of nitrogen per 1000 square feet per year divided into 4 equal applications*** (ref. Stahnke, *Turfgrass pub.EB1280*). This nitrogen can come from inorganic, chemical fertilizers or from the natural breakdown of grass clippings. If left on the lawn, ***grass clippings can provide up to 2lbs of nitrogen per year***, reducing the need for costly chemical fertilizers by one-half. In addition, the degraded clippings add organic matter and beneficial microbes to the soil, which permanently improves soil texture and helps grass resist pests and disease. Finally, unlike commercial fertilizers, grass clippings do not leach salmon-toxic chemicals into streams.

The Grasscycling Method

Proper mowing technique is essential to grasscycling. First, a ***sharp blade*** makes a huge difference. A dull mower blade rips the grass and leaves a torn, ragged plant behind. Torn grass is susceptible to disease and insect infestation. It is easy to sharpen a mower blade at home by removing it and using a file. Alternatively, many shops provide blade-sharpening services. Secondly, it is best to ***cut the grass when it is dry***. Although this advice seems impractical in the Northwest, wet grass cuts poorly and leaves clumps of clippings that cannot filter down to the soil. Finally, ***cut no more than ⅓ of the grass blade (no more than 1") at each mowing.*** Most grass species in Western Washington lawns should be left 2" to 3" tall. Although we think of grass as a green carpet, we must remember that it is a plant, and like any plant, grass derives most of its nutrients from the sun. The grass leaves capture the sun's energy and convert it to plant sugars. If too much of the stem is "pruned" by mowing, the plant must draw nutrients from the soil. Soon the soil is depleted and the grass suffers. ***During periods of heavy growth, it may be necessary to mow the lawn every 4-5 days*** to ensure that no more than ⅓ of the blade is cut off each time, leaving the clippings on the lawn each time. Contrary to popular belief, frequent mowing actually reduces the amount of time spent on lawn care. Frequent mowing is easier on the lawn mower and ensures that there are no clippings to rake and bag. Frequently mowed grass grows thick crowns and deep roots and crowds out weeds. It is more disease and insect resistant. The short clippings left on the lawn filter between the cut blades and break down quickly without leaving clumps.

A Mower for Everyone

From old-fashioned reel mowers to hi-power tractors, there is a lawn mower for everyone. The purist insists on a reel or push mower. ***Reel mowers*** have many advantages. A sharp blade on a reel mower is the safest way to cut grass. As the blade turns, it cuts each grass blade smoothly with little tearing. In addition, reel mowers are quiet, low-maintenance, non-polluting and provide excellent aerobic exercise. Unlike power mowers, reel mowers do not blow grass clippings into the lawn and they tend to leave more grass clippings on the lawn surface. They are inefficient in high grass and may not cut some woody weeds. Most homeowners use ***gas or electric powered non-mulching lawn mowers***. Their relatively low cost and ease of use are their major selling points. The standard power mower simply cuts the grass blade with a rotary blade and discharges it into a bag or onto the lawn. Unless the mower blade is very sharp, power mowers tend to rip the grass rather than cut it smoothly. Mulching blades are available to retrofit any standard power mower. ***Mulching mowers*** are simply power mowers built with a specially designed rotary blade and deeper deck. The blade cuts and pulls clippings into the deep mower deck, where the blades repeatedly re-cut the clippings into tiny particles. Mulching mowers are also useful for shredding leaves and other plant materials before adding them to the compost pile.

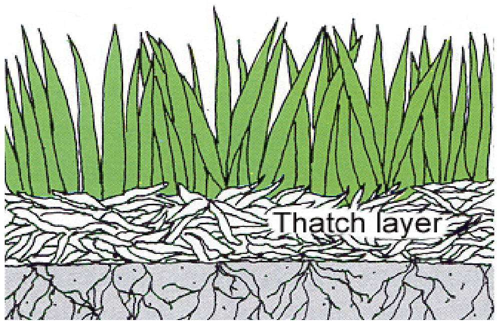
Is grasscycling possible without a mulching mower? Absolutely! If grass clippings are less than 1" long, they will easily filter between the standing grass blades and break down quickly. For longer clippings, simply mow the grass in one direction and go over it the opposite direction. This "criss-cross" mowing technique will effectively mulch the clippings.

Grass Clippings DO NOT CAUSE THATCH

Many homeowners reject grasscycling because they have been told that grass clippings cause thatch.

Thatch is a tight layer of dead and decaying grass roots, rhizomes and stems that lies just above the soil surface (see Fig. 12). Thatch is high in lignins and very resistant to microbial breakdown. In a healthy lawn, earthworms breakdown thatch. ***Thatch is caused by compacted soil, short, frequent watering, fast-acting high nitrogen fertilizers and overzealous use of herbicides and pesticides***. Compacted soil and short, frequent watering encourage shallow rooting. Over application of fertilizers encourages leaf growth instead of deep root growth. Herbicides and

Figure 12. Thatch.



pesticides kill beneficial microbes and earthworms. **LAWN CLIPPINGS DO NOT CAUSE THATCH!** Lawn mowing, *if done properly*, removes only the top ⅓ of the grass blade. Unlike roots, rhizomes and stems, grass leaves (blades) are high in nitrogen, very low in lignins and contribute little to thatch formation. In fact, decomposed clippings are a valuable soil amendment.

A small amount (½" or less) of thatch is beneficial. Thatch increases turf resilience, reduces evaporation and insulates the grass roots. Thatch is only a problem when it exceeds ½" in thickness. As thatch builds up, roots cannot penetrate it and there is a tendency for grass roots to grow in the thatch layer rather than in the soil. Thatch is a poor soil substitute; grass rooted in thatch is prone to drought stress, disease and insects.

How do we determine the level of thatch build-up? The simplest way to measure thatch build-up is to dig up a wedge of grass and soil and measure the amount of thatch. If thatch exceeds ½", it is time to de-thatch. Thatch can be removed manually by vigorous raking or by renting a de-thatcher or power rake. Keep in mind that most of the grass species used in Northwest lawns have a low tendency to form thatch. Most lawns will NEVER need de-thatching.

The best way to prevent thatch is to water deeply and feed the soil.

Frequent, short sprinkling encourages shallow root growth. It is better to wait until the top 2" of soil becomes dry and the grass shows signs of stress. Thirsty grass becomes wilted, dull and less resilient. Most lawns require about 1" of water per week over the entire surface. One inch of water will penetrate anywhere from 4" in clay soils to 12" in sandy soil (ref. Schultz, *The Chemical-Free Lawn*, p.106). It is important to remember that ***the flow rate of your sprinkler should never exceed the infiltration rate of your soil***. If necessary, don't try to water your lawn in one uninterrupted session. Instead, water off and on throughout the day to ensure all water is absorbed. The easiest way to gauge watering depth is to place an empty tuna or cat food can (1" deep) in the path of the sprinkler. When the can is full and your lawn has absorbed all the water, you have watered sufficiently. Expect to water for a long time. Most sprinklers will fill only *one-quarter to one-third of your 1" deep can/hour*. Although it seems wasteful to run the sprinkler for hours, watering deeply and *less frequently* actually saves water.

The Importance of Aeration

As you know, soil feeds the plant. Healthy, loose, permeable soil encourages root growth, and a thicker lawn. The best way to increase the permeability of your soil is aeration followed by a top dressing of finished compost. Most landscape professionals believe that ***lawn aeration is the single most important thing you can do for your lawn.*** Aeration is accomplished by taking ***plugs*** out of the soil. Plugs are basically cylindrically shaped pellets of soil approximately 3½" deep and ½" inch in diameter. For best results, plugs should be spaced about every 3-4" (approx. 8 plugs/sq. ft). Aeration can be done manually using a pitchfork or specially designed aeration tool but it is grueling work. Most landscapers will provide this service, and lawn-aerating machines can be rented at most rental centers. After aeration, apply a thin (approx. ¼") layer of finished compost over the lawn and water in. The compost acts as a time-release fertilizer, improves soil texture and supplies beneficial microbes. In addition, aeration breaks up thatch and the added organic matter encourages earthworms into the thatch layer.

Season by Season Guide to Grasscycling

For a summary of this material and a quick reference guide, see Fig. 13.

Spring (approx. April 15):

- Get your lawn mower blade sharpened.
- Early spring (approximately April 15) is a good time to apply a 3-1-2 chemical fertilizer at the rate of 1 lb. nitrogen per 1000 sq. ft. of lawn. Spring is the time of fastest turf growth and highest nitrogen demand. A slow, timed- release fertilizer derived from organic sources such as blood meal or chicken manure provides more even turf growth and color.
- ***Spring is the best time to aerate the lawn and top dress with finished compost.*** After aeration, apply a thin (approx. ¼") layer of finished compost over the lawn and water in.
- Mow as often as necessary, removing a maximum of ⅓ of the grass blade each mowing and leave the clippings on the lawn. (If clippings are longer, bag and place in your yard waste compost pile.)

Summer (approx. June 15):

- Mow as necessary, removing a maximum of ⅓ of the grass blade each time.
- Leave clippings on lawn. No chemical fertilizers are needed; degrading grass provides adequate nitrogen.
- ***Water deeply and infrequently.***

Fall (approx. Sept. 1):

- Mow as necessary, removing a maximum of ⅓ of the grass blade each time and leave clippings on the lawn.
- If you did not aerate and top dress in the spring, aerate the lawn and top dress with finished compost. After aeration, apply a thin (approx. ¼") layer of finished compost over the lawn and water in.
- Apply lime if necessary (soil pH less than 5.5). It is wise to test the soil pH before adding lime. Soil testing kits are available at most garden stores. Do not apply more than 35lb. per 1000 sq. ft. lawn. Because of the alkalinity of soils in the Columbia Basin, it is unlikely you would need this soil amendment.
- If necessary, de-thatch the lawn. De-thatching is only necessary if thatch has built up over ½".

Winter (from about Nov. 15 – Dec. 7):

- Apply fertilizer. Apply a slow-release, organically based 3-1-2 chemical fertilizer. Apply at the rate of 1 lb. nitrogen per 1000 sq. ft.

- Mow as necessary, removing a maximum of ⅓ of the grass blade each time and leaving clippings on lawn.

C. Tricks of the Trade: Grasscycling Made Easy

Q: I've neglected to mow my lawn and now the grass is over 6" tall. Can I still grasscycle?

A: When grass is left too long, it is best to mow it several times, taking no more than ⅓ its length each time. Since you will generate so many clippings, it is best to bag up all but the last batch. Add them to your compost pile and use the finished compost to top dress the lawn next spring or fall.

Q: I treat my lawn with Weed & Feed. Is it OK to leave the clippings on the lawn?

A: Yes! In fact, you will increase the effectiveness of the herbicide. The clippings will slowly degrade and the residual herbicide will suppress new weed growth. Do keep in mind that herbicides are toxic to beneficial microbes and earthworms. See Chapter 3, Section 10 if you wish to compost Weed & Feed treated grass clippings.

Q: If I leave the clippings on the lawn won't they get tracked all over my house?

A: Grass clippings degrade very quickly. If you use a mulching mower and remove no more than ⅓ of the grass blade each mowing, clippings should almost immediately filter between the standing grass blades and not create a tracking problem. Even if your clippings are a little longer, within 24-48 hours no recognizable clippings should be left on the lawn.

Figure 13. Seasonal Guide to a Great Lawn.

Seasonal Guide to a Great Lawn

Spring (April 15):

- Get mower blade sharpened.
- Aerate and top dress lawn with finished compost.
- Mow as necessary—no more than 1/3 blade.
- Leave clippings unless very long or wet.

(May 15)

- Apply 3-1-2 chemical fertilizer—1lb Nitrogen/1000sq ft.

Summer (June 15):

- Mow as necessary—no more than 1/3 blade.
- Leave clippings on lawn.
- Water deeply and infrequently.

Fall (September 1):

- Mow as necessary—no more than 1/3 blade.
- Leave clippings on lawn.
- Aerate and top dress unless done in spring.
- De-thatch if necessary.
- Apply 3-1-2 chemical fertilizer—1lb Nitrogen/1000sq ft.

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